MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Vol. 113 No. 3 1953

ANNUAL REPORT OF THE COUNCIL

Published and Sold by the
ROYAL ASTRONOMICAL SOCIETY
BURLINGTON HOUSE
LONDON, W. 1

Price Thirteen Shillings and Sixpence

NOTICE TO AUTHORS

1. *Communications.*—Papers must be communicated to the Society by a Fellow. They should be accompanied by a summary at the *beginning* of the paper conveying briefly the content of the paper, and drawing attention to important new information and to the main conclusions. The summary should be intelligible in itself, without reference to the paper, to a reader with some knowledge of the subject; it should not normally exceed 200 words in length. **Authors are requested to submit MSS. in duplicate. These should be typed using double spacing and leaving a margin of not less than one inch on the left-hand side. Corrections to the MSS. should be made in the text and not in the margin.** Unless a paper reaches the Secretaries more than seven days before a Council meeting it will not normally be considered at that meeting. By Council decision, MSS. of accepted papers are retained by the Society for one year after publication; unless their return is then requested by the author, they are destroyed.

2. *Presentation.*—Authors are allowed considerable latitude, but they are requested to follow the general style and arrangement of *Monthly Notices*. References to literature should be given in the standard form, including a date, for printing either as footnotes or in a numbered list at the end of the paper. Each reference should give the **name and initials** of the author cited, irrespective of the occurrence of the name in the text (some latitude being permissible, however, in the case of an author referring to his own work). The following examples indicate the style of reference appropriate for a paper and a book, respectively :—

A. Corlin, *Zs. f. Astrophys.*, **15**, 239, 1938.
H. Jeffreys, *Theory of Probability*, 2nd edn., section 5.45, p. 258, Oxford, 1948.

3. *Notation.*—For technical astronomical terms, authors should conform closely to the recommendations of Commission 3 of the International Astronomical Union (*Trans. I.A.U.*, Vol. VI, p. 345, 1938). Council has decided to adopt the I.A.U. 3-letter abbreviations for constellations where contraction is desirable (Vol. IV, p. 221, 1932). In general matters, authors should follow the recommendations in *Symbols, Signs and Abbreviations* (London : Royal Society, 1951) except where these conflict with I.A.U. practice.

4. *Diagrams.*—**These should be designed to appear upright on the page, drawn about twice the size required in print and prepared for direct photographic reproduction except for the lettering, which should be inserted in pencil. Legends should be given in the manuscript indicating where in the text the figure should appear.** Blocks are retained by the Society for 10 years; unless the author requires them before the end of this period they are then destroyed.

5. *Tables.*—**These should be arranged so that they can be printed upright on the page.**

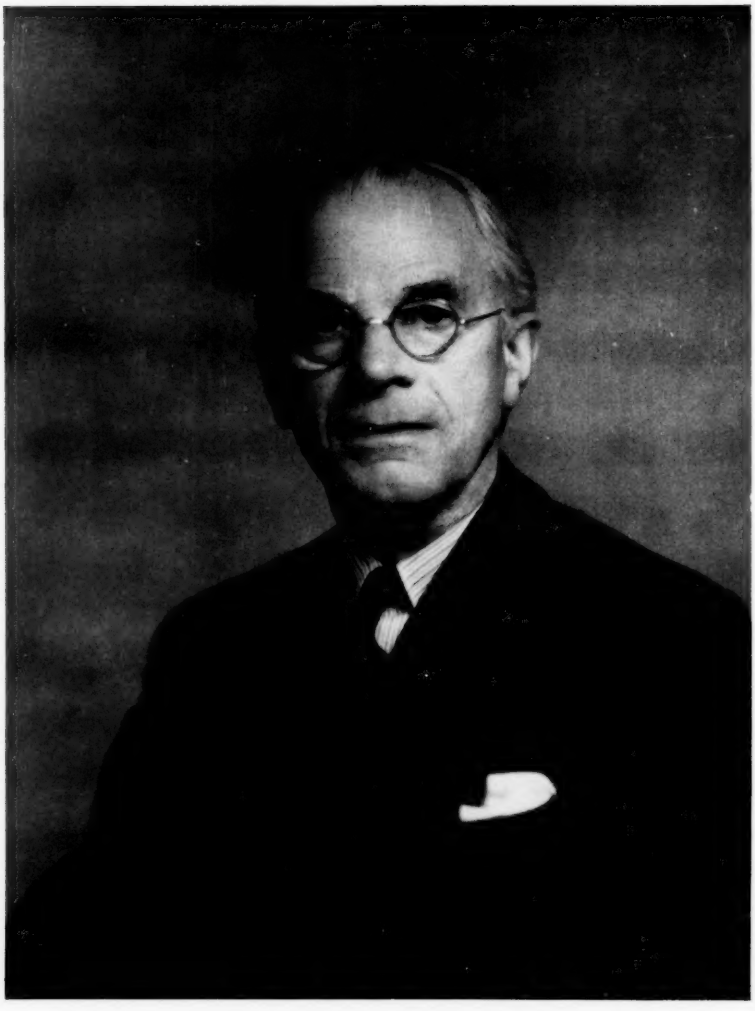
6. *Proofs.*—Costs of alterations exceeding 5 per cent of composition must be borne by the author. Fellows are warned that such costs have risen sharply in recent years, and it is in their own and the Society's interests to seek the maximum conciseness and simplification of symbols and equations consistent with clarity.

7. *Revised Manuscripts.*—When papers are submitted in revised form it is especially requested that they be accompanied by the original MSS.

Reading of Papers at Meetings

8. When submitting papers authors are requested to indicate whether they will be willing and able to read the paper at the next or some subsequent meeting, and approximately how long they would like to be allotted for speaking.

9. Postcards giving the programme of each meeting are issued some days before the meeting concerned. Fellows wishing to receive such cards whether for Ordinary Meetings or for the Geophysical Discussions or both should notify the Assistant Secretary.



Professor H. Dingle, A.R.C.S., D.Sc.
President, 1951–1953

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Vol. 113 No. 3

ANNIVERSARY MEETING OF 1953 FEBRUARY 13

Professor H. Dingle, President, in the Chair

The election by the Council of the following Fellows was duly confirmed :—

Howard George Miles, 1 Copthorne Road, Coventry, Warwickshire (proposed by G. T. Smith-Clarke);

*Alan Francis Moore, Geophysics Department, Imperial College of Science and Technology, London, S.W.7 (proposed by J. McG. Bruckshaw);

Peter John Philpott, B.Sc., H.M.S. *Dolphin*, Gosport, Hampshire (proposed by I. E. Roberts);

Thammanna Ramesan, M.Sc., Royal Holloway College, Englefield Green, Surrey (proposed by W. H. McCrea);

Malcolm P. Savedoff, Ph.D., Sterrewacht te Leiden, Leiden, Holland (proposed by J. H. Oort); and

Radomir Turajlić, B.Sc.(Eng.), Queen's College, Oxford (proposed by S. Chapman).

The election by the Council of the following Junior Member was duly confirmed :—

Robert Michael Loynes, 167 Beccles Road, Gorleston, Great Yarmouth, Norfolk (proposed by G. F. West).

Ninety-eight presents were announced as having been received since the last Meeting, including :—

Martin Davidson (ed.), *Astronomy for everyman* (presented by the editor);

David S. Evans, *Teach yourself astronomy* (presented by the author); and

R. Bock, *Atlas of magnetic declination of Europe for epoch 1944–1945* (presented by the U.S. Army Map Service).

The President then addressed the Meeting on the awards of the Gold Medal to Professor Chandrasekhar, the Eddington Medal to Canon Lemaître and the

* Transferred from Junior Membership.

Jackson-Gwilt Medal and Gift to Mr Prentice, and made the presentations of the Eddington Medal and of the Jackson-Gwilt Medal and Gift. He spoke as follows:—

"A man there was, though some did count him mad,
The more he cast away, the more he had.

I think these words of Bunyan might have been unconsciously in the minds of the Council in recent months, for at a time when financial problems wear a more menacing aspect than perhaps ever before, it has chosen for the first time in our history to present three medals in one year. We can at least hope with some confidence that, whatever the effect on the Treasurer's accounts may be, the return in astronomical knowledge will abundantly justify the outlay.

"The Gold Medal, which has always been and still remains the Society's highest award, has this year been bestowed on Professor Subrahmanyan Chandrasekhar for his contributions to mathematical astrophysics. There are several reasons why it is inappropriate for me now to give an account of the very important work which has been thus recognized. It is enormous in quantity, and our time is very brief; it is, however, not of a kind that lends itself to condensation even by an expert in the subject, which I cannot claim to be; and further, we hope in a few months to hear Professor Chandrasekhar himself speak on that aspect of it which he considers most suitable when he delivers the George Darwin Lecture for this year. All I would say now, therefore, is that the scope of Professor Chandrasekhar's work is indicated by the titles of his three books—*An Introduction to the Study of Stellar Structure; Principles of Stellar Dynamics;* and *Radiative Transfer*—and that the treatment has been of the most fundamental character. His main concern has been to establish, and to define the scope of, mathematical theorems which are likely to be of use in astrophysical investigations; their application to particular problems has been a secondary interest. It follows that much of the value of this work for astronomy is likely to be realized in the future more than in the present, but that has seemed to the Council no reason for delaying recognition of it. This Society has never been narrow in its view of astronomy, and it has not hesitated to sponsor mathematical, physical and other investigations that may reasonably be expected to contribute ultimately to the advancement of astronomical knowledge. In honouring such work as that of Professor Chandrasekhar it honours itself and maintains the traditions which its illustrious Fellows of the past have bequeathed to it.

"But if the Gold Medal remains our highest honour, I think the greatest interest this year belongs to the award of the Eddington Medal, for this is the first occasion on which this tribute to the memory of one of the greatest of our Fellows has been paid. It will doubtless be remembered that the rules governing our procedure in this matter prescribe that the Medal shall preferably be given for outstanding work in one of the fields of interest of the late Sir Arthur Eddington. His interests were so wide that this is not a very severe restriction, although inevitably, as time goes on and new branches of astronomy develop from the parent stem, a certain liberality of interpretation of the rule will become permissible. But for the first award it is fitting that the relation of the work of the medallist to that of Eddington himself should be as close as possible, and with that desideratum in view the Council could have made no more appropriate choice than Canon Georges Lemaître. The great work to which Eddington devoted the last years

of his life was inseparably bound up with a view of the universe for which he was largely indebted to Lemaître. 'The proof of the instability of the Einstein configuration,' wrote Eddington in his book, *The Expanding Universe*, 'was the turning-point in my own outlook', and that proof he found in Lemaître's work.

"The story is well known, but it can be retold so briefly that we may allow ourselves the pleasure of hearing it once more. Einstein's theory of relativity, with its new law of gravitation, made possible an entirely new approach to the old problem of the character of the universe as a whole. The long-felt difficulty arising from the impossibility of imagining the universe to be either bounded or infinite was given a new form; it now became legitimate to regard the universe as both finite and unbounded. True, this seems to present equally great difficulties to the imagination, but such a system, if not imaginable, could be conceived, and its form could be expressed by precise mathematical equations from which deductions could be drawn. Einstein himself formulated the first description, which was that of a universe containing a finite amount of matter, evenly distributed and on the whole static, i.e. getting neither larger nor smaller with the passage of time. An alternative universe was shortly afterwards described by de Sitter, which continually expanded or contracted. This soon became rather more than a curiosity because the phenomenon now known as the systematic recession of the extra-galactic nebulae was just coming to light, and this suggested that if the system of nebulae could properly be identified with the universe, the universe was built on the de Sitter rather than the Einstein model. Unfortunately, however, the de Sitter universe was necessarily empty, so that it was impossible to identify the two. The situation was saved by the work of our medallist. He showed that the equations of general relativity, even though one still restricted oneself to uniformly distributed systems, permitted a third type of solution, corresponding to a universe which contained matter and also continually expanded or contracted. This was indeed the kind of system which the nebulae presented to observation, and accordingly, for the first time since the universe of revolving spheres collapsed at the beginning of the seventeenth century, a harmonization in general terms was established between the universe which could be observed and the universe which could be legitimately conceived in terms of accepted physical theory.

"Lemaître had been anticipated by Friedmann, but this was unknown to him at the time, and to most others also. Eddington, in fact, was at first ignorant not only of Friedmann's work but also of Lemaître's, and was himself working on the problem of the stability of the Einstein universe. When he at last discovered Lemaître's paper he saw at once that it solved his problem: the Einstein universe was unstable. He accordingly took the view, which he maintained to the end of his life, that the history of the actual universe was as follows. It began as an Einstein universe; because of its inherent instability, however, this began at some instant to expand and so became a Lemaître universe, which it now is; it is approaching asymptotically to the de Sitter state which it will reach at an infinitely distant time. Lemaître himself has developed a different view. He regards the earliest state of the universe as that of a 'primitive atom' which, instead of beginning to expand with the extreme gentleness which Eddington contemplated, burst asunder with explosive violence. The receding galaxies are the fragments resulting from this event. We are not concerned now with these differences. Whatever the truth of the matter may be, the work of Eddington

Jackson-Gwilt Medal and Gift to Mr Prentice, and made the presentations of the Eddington Medal and of the Jackson-Gwilt Medal and Gift. He spoke as follows:—

"A man there was, though some did count him mad,
The more he cast away, the more he had.

I think these words of Bunyan might have been unconsciously in the minds of the Council in recent months, for at a time when financial problems wear a more menacing aspect than perhaps ever before, it has chosen for the first time in our history to present three medals in one year. We can at least hope with some confidence that, whatever the effect on the Treasurer's accounts may be, the return in astronomical knowledge will abundantly justify the outlay.

"The Gold Medal, which has always been and still remains the Society's highest award, has this year been bestowed on Professor Subrahmanyan Chandrasekhar for his contributions to mathematical astrophysics. There are several reasons why it is inappropriate for me now to give an account of the very important work which has been thus recognized. It is enormous in quantity, and our time is very brief; it is, however, not of a kind that lends itself to condensation even by an expert in the subject, which I cannot claim to be; and further, we hope in a few months to hear Professor Chandrasekhar himself speak on that aspect of it which he considers most suitable when he delivers the George Darwin Lecture for this year. All I would say now, therefore, is that the scope of Professor Chandrasekhar's work is indicated by the titles of his three books—*An Introduction to the Study of Stellar Structure; Principles of Stellar Dynamics;* and *Radiative Transfer*—and that the treatment has been of the most fundamental character. His main concern has been to establish, and to define the scope of, mathematical theorems which are likely to be of use in astrophysical investigations; their application to particular problems has been a secondary interest. It follows that much of the value of this work for astronomy is likely to be realized in the future more than in the present, but that has seemed to the Council no reason for delaying recognition of it. This Society has never been narrow in its view of astronomy, and it has not hesitated to sponsor mathematical, physical and other investigations that may reasonably be expected to contribute ultimately to the advancement of astronomical knowledge. In honouring such work as that of Professor Chandrasekhar it honours itself and maintains the traditions which its illustrious Fellows of the past have bequeathed to it.

"But if the Gold Medal remains our highest honour, I think the greatest interest this year belongs to the award of the Eddington Medal, for this is the first occasion on which this tribute to the memory of one of the greatest of our Fellows has been paid. It will doubtless be remembered that the rules governing our procedure in this matter prescribe that the Medal shall preferably be given for outstanding work in one of the fields of interest of the late Sir Arthur Eddington. His interests were so wide that this is not a very severe restriction, although inevitably, as time goes on and new branches of astronomy develop from the parent stem, a certain liberality of interpretation of the rule will become permissible. But for the first award it is fitting that the relation of the work of the medallist to that of Eddington himself should be as close as possible, and with that desideratum in view the Council could have made no more appropriate choice than Canon Georges Lemaître. The great work to which Eddington devoted the last years

of his life was inseparably bound up with a view of the universe for which he was largely indebted to Lemaître. 'The proof of the instability of the Einstein configuration,' wrote Eddington in his book, *The Expanding Universe*, 'was the turning-point in my own outlook', and that proof he found in Lemaître's work.

"The story is well known, but it can be retold so briefly that we may allow ourselves the pleasure of hearing it once more. Einstein's theory of relativity, with its new law of gravitation, made possible an entirely new approach to the old problem of the character of the universe as a whole. The long-felt difficulty arising from the impossibility of imagining the universe to be either bounded or infinite was given a new form; it now became legitimate to regard the universe as both finite and unbounded. True, this seems to present equally great difficulties to the imagination, but such a system, if not imaginable, could be conceived, and its form could be expressed by precise mathematical equations from which deductions could be drawn. Einstein himself formulated the first description, which was that of a universe containing a finite amount of matter, evenly distributed and on the whole static, i.e. getting neither larger nor smaller with the passage of time. An alternative universe was shortly afterwards described by de Sitter, which continually expanded or contracted. This soon became rather more than a curiosity because the phenomenon now known as the systematic recession of the extra-galactic nebulae was just coming to light, and this suggested that if the system of nebulae could properly be identified with the universe, the universe was built on the de Sitter rather than the Einstein model. Unfortunately, however, the de Sitter universe was necessarily empty, so that it was impossible to identify the two. The situation was saved by the work of our medallist. He showed that the equations of general relativity, even though one still restricted oneself to uniformly distributed systems, permitted a third type of solution, corresponding to a universe which contained matter and also continually expanded or contracted. This was indeed the kind of system which the nebulae presented to observation, and accordingly, for the first time since the universe of revolving spheres collapsed at the beginning of the seventeenth century, a harmonization in general terms was established between the universe which could be observed and the universe which could be legitimately conceived in terms of accepted physical theory.

"Lemaître had been anticipated by Friedmann, but this was unknown to him at the time, and to most others also. Eddington, in fact, was at first ignorant not only of Friedmann's work but also of Lemaître's, and was himself working on the problem of the stability of the Einstein universe. When he at last discovered Lemaître's paper he saw at once that it solved his problem: the Einstein universe was unstable. He accordingly took the view, which he maintained to the end of his life, that the history of the actual universe was as follows. It began as an Einstein universe; because of its inherent instability, however, this began at some instant to expand and so became a Lemaître universe, which it now is; it is approaching asymptotically to the de Sitter state which it will reach at an infinitely distant time. Lemaître himself has developed a different view. He regards the earliest state of the universe as that of a 'primitive atom' which, instead of beginning to expand with the extreme gentleness which Eddington contemplated, burst asunder with explosive violence. The receding galaxies are the fragments resulting from this event. We are not concerned now with these differences. Whatever the truth of the matter may be, the work of Eddington

is so closely bound up with that of Lemaître that it is impossible to consider the one apart from the other.

"We are happy to welcome Canon Lemaître here this afternoon to receive a medal which I am sure he will treasure no more for the testimony which it bears to his own outstanding work than for the memory which it will recall of one with whom he worked in friendship and with mutual profit. We wish him success in his future labours, and indeed we have a right to expect that he will give us further cause for gratitude. There are other laws in the universe besides the mathematical ones; there is, for instance, the law of compensation of which Emerson wrote so eloquently and which we can see operating here and now. To Einstein space was static, but time went inexorably on. Lemaître made space expand, but the law of compensation ordained that for him time should stand still. With others, age takes its inevitable toll; the face becomes lined, the hair grey, the step falters. Not so with Lemaître. The face that looks benignly at us from the photograph of the International Astronomical Union at Cambridge in 1925 is the same face that we see today. In presenting you with the first Eddington Medal, 'Peter Pan' Lemaître, we assure you of our admiration for your past work and of that gratitude that has been defined as a lively expectation of favours yet to come.

"One of the achievements for which the Hannah Jackson (*née* Gwilt) Medal and Gift are awarded is 'the discovery of a new heavenly body'. During the twenty years ending with the outbreak of the second World War, Mr John Philip Manning Prentice discovered and recorded nearly 19000. There is a suggestion of immodesty about so gross an over-qualification, but this has not prevented him from continuing the good work, and I infer from information supplied by my kind mentor, Dr J. G. Porter, that his total now must be in the neighbourhood of 30000. All but one of these are meteors, but the other is literally a star turn—Nova Herculis of 1934 December 13. Of the meteors I think it may truly be said that while he counts their numbers he does not call their names, but it is probably his invention of pet names for the faintest visible stars that gave him the intimate familiarity with the heavens necessary for the discovery of the nova at about the 3rd magnitude. Discoveries of this kind are made only by those who combine a detailed knowledge of the sky with unwearied persistence in observing. Such men are few, and their value to astronomy cannot be estimated.

"But Prentice's life-work has been the determination of meteor radiants, and here it may truly be said that he has caused a revolution. He was appointed Director of the B.A.A. Meteor Section in 1923 at the age of 20, and he has remained in that position ever since, guiding the observing procedure and reducing the results of the observations of that devoted band who give freely of their time and labour to this least spectacular field of our subject. Time does not permit of an account of the new techniques which he introduced or of his work on what he has called 'radiant structure'. I can say only that it is of the highest order of skill and importance. Meteor observing was perhaps the last branch of astronomy to remain a purely human pursuit. Science slowly but surely displaces the man by the instrument, and now even here it may be said that

> Her prentice han' she tried on man,
> An' then she made the radio.

It would scarcely have been unpardonable if Prentice has shown some resentment at this threat to his own preserve. In fact, no one could have been more helpful, and the observers at Jodrell Bank will, I am sure, be glad to acknowledge the debt they owe to his great experience and knowledge, placed ungrudgingly at their disposal in the early stages of their work.

"Mr Prentice, the Society is proud to enrol you in the distinguished band of its medallists, and I ask you to accept this testimony of our admiration and goodwill."

The President then delivered his address on "Science and Modern Cosmology" (see p. 393). A vote of thanks for the address was moved by Professor W. H. McCrea, seconded by Mr C. A. Ronan and carried with acclamation.

The President adjourned the Meeting till 1953 March 13, asked Junior Members and strangers to leave, and declared the Annual General Meeting convened.

ANNUAL GENERAL MEETING OF 1953 FEBRUARY 13

Professor H. Dingle, President, in the Chair

The Minutes of the preceding Annual General Meeting were read, confirmed and signed.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year.

The Secretary read extracts from the Narrative Report of the Council.

The Secretary, on behalf of the Council, moved the adoption of the amended Bye-law No. 22 below, explaining that the alteration in wording of the last sentence was designed to give the Council the same power to waive the normal Admission Fee in the case of a former Junior Member as in the case of a former Fellow :—

> 22. The contribution of each Fellow shall, for the first year, be five guineas, or three guineas, according to the month in which he may have been elected (viz. two guineas in all cases as an admission fee, and three guineas as the first year's contribution, if such election has taken place in the month of January, February, March, April, May or June; but only one guinea as the first year's contribution if such election has taken place in the month of October, November or December), payable at the time of his election; and three guineas for every subsequent year; the first of such subsequent contributions to become due and be payable in advance on the 1st day of January in every subsequent year. In the event of a former Fellow seeking re-election, or of a former Junior Member seeking election as a Fellow, the Council may, if it thinks fit, waive the admission fee normally payable, it being understood that in all such cases the individual concerned must be formally proposed and submitted for election as provided in Bye-laws 13 to 20, apart from the payment of the admission fee.

The motion was carried *nem. con.*

The Secretary, on behalf of the Council, moved the adoption of the amended Bye-law 85 below, which was intended to ensure that the Society could claim the

benefits of the Scientific Societies Act of 1843 in the matter of exemption from payment of local rates:—

> 85. The whole of the funded property of the Society shall be placed in the name of "The Royal Astronomical Society". The Society shall not make any dividend, gift, division, or bonus in money unto or between any of its members.

The motion was carried *nem. con.*

The Report of the Honorary Auditors was read (see p. 281).

The Deputy Treasurer gave a brief explanation of the accounts and a survey of the Society's financial position.

A vote of thanks to the Honorary Auditors of the Treasurer's accounts for 1952 was proposed and carried unanimously.

It was proposed and carried that the Report of the Council be received and adopted, and that it be printed and circulated in the usual manner, together with the Report of the Honorary Auditors and the President's Address.

The Scrutineers reported to the President the result of the ballot, and names of the Officers and Council elected for the ensuing year were read to the Meeting. (The list of names is given on p. 408.) At the invitation of the retiring President, the new President, Dr J. Jackson, took the Chair amid applause, and briefly expressed his thanks to the Fellows for the honour they had done him.

The thanks of the Society were given to the retiring President (Professor H. Dingle), Vice-Presidents (Sir Harold Spencer Jones and Professor H. S. W. Massey), and other members of Council.

The thanks of the Meeting were given to the Scrutineers of the ballot.

The Meeting then adjourned till 1954 February 12.

REPORT OF THE COUNCIL TO THE HUNDRED AND THIRTY-THIRD ANNUAL GENERAL MEETING OF THE SOCIETY

This Report refers to the calendar year 1952.

1. *Royal Patronage.*—The opening of the year was darkened by the sudden death of H.M. King George VI, who had throughout his reign been (like his royal predecessors from the days of King William IV) Patron of the Society. British astronomers throughout the Commonwealth and Empire joined in paying tribute to his late Majesty's unsparing devotion to duty in loyal Addresses of Condolence to H.M. the Queen and to Queen Elizabeth the Queen Mother (see pp. 246, 247). In a further Address to H.M. the Queen, the President asked that she continue the Royal Patronage hitherto extended by the Sovereign to the Society. Her Majesty graciously consented to this, and has now signed the Roll as Patron.

2. *Membership.*—The slow but steady increase in the Society's membership continues (see table on p. 281). The institution of Junior Membership five years ago has had gratifying results in introducing young people to the advantages that Fellowship offers. A certain inflexibility in the existing Bye-laws has on occasion, however, denied to a Junior Member, on the expiry of his term of membership, the privilege of taking up Fellowship without payment of the Admission Fee. Lest this should prove a deterrent, a modification of the Bye-laws to be proposed on behalf of the Council at this Annual General Meeting (see p. 273) seeks to remove this inflexibility by giving the Council power to waive payment of the Admission Fee in suitable circumstances.

The Society lost by death during the year the following Associate :

M. Bernard Lyot

and the following Fellows :

*Charles Frederick Arden-Close
Basil Staunton Batty
Harold Whittaker Browne
*Charles Pritchard Butler
*Jnan Saran Chakravarti
*Thomas Folkes Claxton
Peter Doig
James Molesworth Franklin Dumphreys
*Herbert Henry Furner
*Richard Arman Gregory
Wilfred Hall
William Hodge
*William Jacob Jones
George Lyman
Theodore MacKenzie
*John Maurus Moorat
Ernest Valentine Payne
Gordon Peace
*Arthur Henry Phayre
*Edward C. Phillips
Richard Griffith Quirk
Harry B. Rumrill
Hugh Simmons
Frank Melson Wingate
Thomas Petty Witter

* Life Fellow.

Obituary Notices of many of these appear on pp. 294–307.

3. *Finance.*—The Treasurer's accounts (pp. 282–286) appear this year in a slightly modified form. On the advice of the professional auditors, the Cash Account is no longer presented: to Fellows unacquainted with the method of its compilation it might have been misleading (not all the items it recorded necessarily referred to the nominal year, for example), and it was costly both to prepare and to audit. The Revenue Account, which gives a much more strictly relevant statement of the year's financial transactions, has been somewhat amplified in order to keep Fellows informed about items which formerly appeared in detail only in the Cash Account.

The Society has undertaken during the year unusually heavy expenditure on repairs and redecoration and on staff retirement gratuities; expenditure which has more than swallowed up the amounts placed to reserve in these categories in last year's accounts. Against a welcome drop in the price of paper must be set a further increase of $2\frac{1}{2}$ per cent in printing charges to cover a cost-of-living bonus granted generally to employees in the trade. A mounting loss on the sale of offprints to authors has been checked by a $33\frac{1}{3}$ per cent increase in the scale of charges, the necessity for which is regretted but is inescapable.

The Society is once again indebted to the Royal Society for a substantial allocation from the Parliamentary Grant-in-Aid of Scientific Publications, on this occasion of £800, of which £50 is earmarked for library purposes. Welcome though this is, no Treasurer can feel easy at a state of affairs in which a precarious approach to balance (this year represented by a deficit of £468) can be achieved only by recurrent allocations from a direct Exchequer grant. It is still more disturbing that the future of the covenant scheme, so far as annual subscriptions are concerned, may depend on the outcome of litigation now before the House of Lords. This can scarcely affect current income, however (this year the total amount of income tax recovered on seven-year covenants reached £454 9*s.* 1*d.*), and it remains true that the most effective action the individual Fellow can take to help the Society's finances is to pay his annual contributions under a seven-year covenant. If he is liable to the full rate of United Kingdom income tax (and no other Fellow is asked to participate*) this will, at no cost to himself, almost double the cash value to the Society of his annual payment

Since 1843 the Society has been exempt, under the Scientific Societies Act of that year, from the payment of local rates on the premises it occupies. With the recent transfer of valuation from the local authorities to the Inland Revenue a query has arisen concerning the eligibility of the Society under the Act, which lays down *inter alia* that a body wishing to benefit from its provisions must be precluded by its Bye-laws from making any division of its assets amongst its members. A formal addition to the Bye-laws in this sense, to be proposed at this Annual General Meeting, will, if passed, put the matter beyond doubt.

4. *Meetings.*—The usual eight Ordinary Meetings took place at Burlington House in 1952, and the five Geophysical Discussions also held attracted good audiences.

The Society was enabled to meet at Leeds on 1952 July 23–26 through the hospitality of the University of Leeds and with the cooperation of the Leeds

* The Inland Revenue authorities state that "A covenantor will still have to pay tax at the standard rate on an annual payment under an effective Deed even if he is personally not liable to tax at the standard rate or even if he is exempt from paying income tax".

Astronomical Society. The thanks of this Society have been tendered to the Vice-Chancellor for the informal reception at which Fellows were welcomed in the magnificent Central Court of the Parkinson Building; to Professor E. C. Stoner, through whose kindness the Physics Lecture Theatre was made available throughout the meetings; to Professor A. C. B. Lovell, who delivered a well-attended lecture on Radio Astronomy on July 24; and to those who gave their time as guides to Fellows during visits to Fountains Abbey, to York Minster, to the Yorkshire Museum and to the works of Messrs. Cooke, Troughton and Simms. Local arrangements were in the hands of Professor T. G. Cowling, to whose energy and unsparing devotion to detail must be attributed the smoothness with which these summer meetings went off.

The George Darwin Lecture for 1952, originally arranged for the October meeting, had to be postponed because Dr Hubble found it impossible to leave the United States at that time. Fellows will be able to hear Dr Hubble deliver the Lecture at Burlington House on 1953 May 8.

The Rome meeting of the International Astronomical Union attracted to Europe a number of astronomers from overseas, some of whom prolonged their stay long enough to attend meetings of the Society. During the year Fellows were able to welcome the following: Dr C. Payne-Gaposchkin (Harvard), Dr J. Larink (Hamburg), Professor A. V. Douglas (Queen's University, Ontario), Dr H. Knox-Shaw (lately of Pretoria), Professor H. A. Brück (Dunsink), Mr J. Hargreaves (Ottawa), Professor Y. Hagihara (Tokyo), Dr R. H. Stoy (Cape), Dr T. L. Page (Washington), Mr A. Shapley, Jr. (National Bureau of Standards, Washington), Miss M. Harwood (Nantucket), Dr M. K. V. Bappu (Mt. Palomar) and Dr P. Wellmann (Hamburg).

5. *Publications.*—During the year 1952 the Society published and distributed the following:

Monthly Notices, Vol. **111**, Nos. 4, 5, 6; Vol. **112**, Nos. 1, 2, 3.
Geophysical Supplement, Vol. **6**, Nos. 5, 6.

At the end of December *Monthly Notices*, **112**, No. 4 and *Occasional Notes* No. 14 were ready for distribution.

Though there is nothing that can properly be described as arrears of printing to be overtaken, it remains the case that the interval between communication of a paper and its appearance in print is disappointingly long. Part of this delay is inherent in the system of refereeing, by which in most instances a paper goes to at least one referee, who is appointed in full Council and whose report is subsequently considered in full Council; part is due to the fact that Editorship of the Society's publications is a task undertaken by honorary officers whose leisure is far from unlimited; and part is due to a printing schedule that is outside the Society's control. Cooperation at all stages between authors, referees, editors and printers is necessary to prevent disruption of the scheduled programme. It is gratifying to record that enhancement of this cooperation during 1952 has led to some narrowing of the gap. Little further improvement can however be expected, if the standard of the Society's publications is to be maintained at its present high level, unless some drastic change of procedure, at present not contemplated, is introduced.

6. " *The Observatory* " *magazine.*—In accordance with the current agreement with the Editors of *The Observatory*, the Society's block annual subscription was raised, as from the beginning of 1952, from £160 to £190. This increase follows an agreed sliding scale relating the block payment to the price of the magazine to outside subscribers, and the latter was raised in 1951.

The current five-year agreement ends with the year 1952. In the belief that the arrangement has brought substantial benefit to both sides over the last ten years, a new agreement has been negotiated, to operate from the beginning of 1953. The new agreement is not specifically determined, though it can be ended at six months' notice by either side; and the sliding scale has been abandoned. The block subscription of £190 may be varied by mutual consent to meet changed circumstances.

7. *Awards.*—The Gold Medal for 1952 was awarded to Dr John Jackson for his work on stellar parallaxes and his contributions to the general problems of star positions and proper motions. The presentation was made at the Anniversary Meeting in February, immediately after the Presidential Address on the award (*M.N.*, **112,** 345).

As mentioned in the last Report, the first award of the Eddington Medal will not be made before 1953.

Dr G. M. Clemence (Director of the Nautical Almanac Office, U.S. Naval Observatory, Washington) and Dr O. Heckmann (Director, Hamburg Observatory) were elected Associates during the year.

8. *The Library.*—The reclassification and reorganization of the Library proceeds according to plan. A great step forward was made possible by its closure during 1952 July, August and September. The decision to close was not made without the most careful consideration of the effect such a step would have on the convenience of Fellows; but it was decided that the advantages of three months' uninterrupted work on the Main Library by a staff only temporarily enhanced in number outweighed by a considerable margin the inevitable inconvenience to users. In its rearranged state the Main Library will be devoted to books on astronomy and a very few sets of the most important periodicals. As to the Library as a whole, about half the books, a quarter of the periodicals and nearly all the pamphlets have been reclassified and provided with accession labels, and are now in their permanent places.

It is inevitable that for the time being books not yet in their permanent places are difficult of access to Fellows unaided, but there can be no doubt that the Library when rearranged will be of greater benefit to Fellows than it has been hitherto. The classified catalogue has already proved its value in many instances. The present indications are that the reorganization will be nearing completion by the end of 1953 August, when Mr Kenedy's appointment ends. The help of a trained assistant has been of great value, not only on account of the additional progress made but also by relieving the Librarian of the heavy physical work of rearrangement. Miss Wadsworth's appointment as part-time Librarian has been renewed for 1953: it is intended that by the end of that year a young assistant, not necessarily with full professional qualifications,

will have been engaged and will have acquired sufficient experience to do the work of the Library more as a matter of office routine than was possible before the reorganization.

9. *The Society's Premises.*—Last year's report mentioned a Ministry of Works list of items of repair, cleaning or redecoration. Most of these matters, including the repair of war-damaged ceilings on the top floor and redecoration of the main staircase, were attended to during the 1952 recess. Some items deferred pending the completion of the library reorganization will, it is hoped, be finished during 1953.

10. *Miscellaneous.*—On the recommendation of its Photographic and Instruments Committee the Council has decided to make available to the general public copies of slides and prints in the Society's collection. These have hitherto been reserved for sale to Fellows only, but there seemed no valid reason why any distinction should be made between photographs in the main collection and the new ones now arriving from Mt. Palomar, which are, by agreement with the copyright holders, on public sale. A new edition of the Catalogue of Slides and Prints is now in press and the new arrangements will be given wider publicity when it is published. The Society's collection of cine-films will remain available on loan to Fellows only. By arrangement with Messrs Autotype Ltd. the Society's working negatives will in future be stored at the firm's premises. This will eliminate the risk of breakage in transit when a batch of prints is ordered to renew stocks.

Fellows will have noted with disquiet a Parliamentary answer by which it appears that plans for the projected Science Centre in London have been shelved. It is hoped that this is a temporary measure only; though with a project of such magnitude, in times of such pressure on the Exchequer, postponement is all too likely to become, in fact if not in intent, indefinite.

The Council has discussed during the year a proposal that Ordinary Meetings should be held on Wednesdays instead of Fridays. It has been pointed out that facilities for cheap rail travel to London from the Home Counties are restricted to days in the middle of the week, and that such a change would result in a substantial saving to many Fellows. Whilst not unmindful of this aspect, the Council took the view that the proposed change would altogether deter many other Fellows, especially those coming from rather farther afield, from attending meetings because of the necessity to sacrifice two mid-week days to travelling instead of one week-day and Saturday. No change is therefore proposed.

Many of the early issues of the *Geophysical Supplement* are and have long been out of print. In response to a request from the U.S. Society of Exploration Geophysicists, the Council has agreed that not more than 50 copies of Vols. 1 to 5 may be reproduced on micro-cards by that Society for distribution to libraries.

The microfilm copies of certain of the Society's irreplaceable documents referred to in last year's Report have been deposited, by kind permission of the Director, at the Norman Lockyer Observatory, Sidmouth.

The Society's Harrison clock, which was lent during the summer to the British Horological Institute for its exhibition entitled " The British Clockmaker's Heritage " now once again graces the Grove-Hills Library.

During the recess the Society lost by retirement the resident porter and his wife. Mr and Mrs Steel had served the Society well for over 27 years and at a brief ceremony at the November meeting the President handed them a retirement present in the form of a cheque. They are succeeded by Mr and Mrs G. H. Gibbs. Mrs S. Oliver, Junior Assistant for the past year, was succeeded on her resignation in April by Miss E. Stanley.

Representatives of the Society were appointed during the year as follows:

on the Board of Management of the Isaac Newton Observatory,

Professor C. W. Allen;

on the Board of Visitors of the Royal Greenwich Observatory,

Professor C. W. Allen.

REPORT OF THE HONORARY AUDITORS FOR THE YEAR 1952

We have examined the professionally audited accounts of the Society. We have checked the official list of Fellows against subscriptions received, and regret to report that the number of Fellows in arrears has increased substantially so bringing the amount owing to the Society to over £400.

On examining the premises of the Society we noted with satisfaction the decoration of the staircase and modifications in the basement accommodation.

We recommend that attention be given to the improvement of the filing system for office records. We also recommend the redecoration of the second floor kitchen.

We acknowledge with gratitude the help and cooperation given us by the Assistant Secretary in providing the information that we required.

K. C. BLACKWELL

R. H. GARSTANG

PROGRESS AND PRESENT STATE OF THE SOCIETY

	Patron	Institutional Members	Fellows		Junior Members	Associates	Total
			Compounders	Annual Contributors			
1951 December 31	1	6	210	773	39	50	1079
Resignations effective 1951 December 31		...	...	−11	...	...	−11
1952 January 1	1	6	210	762	39	50	1068
Since elected		...	1	62	7	2	72
Junior Members elected to Fellowship ...		...	...	8	−8	...	...
Fellow re-elected		...	...	1	...	...	1
Deceased 1952		...	−10	−12	...	−1	−23
Deceased 1951, notified in 1952		...	− 1	− 2	...	...	− 3
Since compounded		...	6	− 6	...	...	...
Resigned 1952		...	...	−10	−4	...	−14
Names removed		...	...	...	−2	...	− 2
Resigned 1951, notified in 1952		...	...	− 1	...	...	− 1
1953 January 1	1	6	206	802	32	51	1098

(N.B.—Twelve Associates are also Fellows, and are therefore counted twice in the above table.)

Dr. *General Fund Revenue Account*

	£ s. d.	£ s. d.
To Salaries and Wages, including Pension Premiums and National Insurance		1,877 6 9
,, Insurance and Telephone		48 16 10
,, Printing, etc.		
Monthly Notices, Vol. 112	2,408 16 7	
Geophysical Supplement, Vol. 6, Nos. 5 and 6	457 10 11	
Occasional Notes, Vol. 2, No. 14	120 0 0	
Photo-engraving	254 16 3	
Slide Catalogue	95 0 0	
Paper supply	514 13 0	
Miscellaneous printing and carriage	214 0 8	
	4,064 17 5	
Adjustments *Monthly Notices*, Vols. 110 and 111, and *Geophysical Supplement*, Vol. 6, No. 4	409 18 8	
	4,474 16 1	
Less Amount received for 1952 from the Parliamentary Grant-in-Aid for Scientific Publications through the Royal Society	750 0 0	
		3,724 16 1
,, Posting and Packing		246 8 11
General Expenses :—		
Stationery and Office Expenses...	162 12 11	
Lighting and Heating	213 8 5	
Travelling Expenses	23 8 1	
Subscriptions to National Central Library and A.S.L.I.B. ...	4 4 0	
Accountants' Fees	63 0 0	
Gold Medal	24 3 4	
Furniture and Fittings, including repairs	236 0 7	
I.A.U. Telegram Service	6 1 9	
House Expenses	89 7 6	
Meeting Expenses	49 17 3	
Library Expenses	20 15 5	
Sundries	45 14 8	
		938 13 11
,, Block Subscription to *The Observatory*		190 0 0
,, Purchase of Books from Potter Fund		9 17 0
,, Reserve for Repairs		300 0 0
,, Binding of Periodicals, etc. (after adjusting Reserves)		187 3 4
,, Reproduction of Photographic Slides and Prints		103 2 4
,, Films, Hire and Expenses		6 14 11
,, Reprint Expenses		7 10 0
		£7,640 10 1

One Year to 1952 *December* 31 *Cr.*

	£	s.	d.	£	s.	d.	£	s.	d.
By *Amounts received from Members* :—									
6 Partial Annual Contributions for 1950 ...	6	6	0						
2 Annual Contributions for 1950	6	6	0						
7 Partial Annual Contributions for 1951 ...	7	7	0						
29 Annual Contributions for 1951	91	7	0						
17 Admission Fees, 1951	35	14	0						
17 First Contributions, 1951	17	17	0						
1 Junior Member's Annual Contribution, 1951	1	1	0						
671 Annual Contributions, 1952	2,113	13	0						
14 Partial Payments, 1952	20	15	0						
6 Institutional Membership Fees, 1952 ...	18	18	0						
34 Junior Members' Annual Contributions ...	35	14	0						
51 Admission Fees	107	2	0						
58 First Contributions	155	8	0						
				2,617	8	0			
Income Tax recovered on those under covenant				427	10	0			
,, *Composition Fee* :—									
Reduced Fee	242	11	0						
Add Special donations from Compounders (including £26 0s. 1*d.* tax recovered on covenants)	65	13	11						
	308	4	11						
Less Transferred to Reserve Account ...	308	4	11						
	–	–	–						
Add Amount brought to Credit for the year	162	14	1						
				162	14	1			
							3,207	12	1
,, Interest and Dividends received (gross)				1,086	6	2			
,, Interest received on Bank Deposit Accounts ...				134	14	0			
							1,221	0	2
,, Sales of Publications, Photographs and Miscellaneous Receipts for the year :									
Monthly Notices, Vol. 110 and earlier				58	19	4			
,, ,, Vol. 111				59	0	3			
,, ,, Vol. 112				1,118	12	8			
Geophysical Supplement				340	6	6			
Memoirs, *Occasional Notes* and Miscellaneous				55	7	7			
Reprints				646	7	5			
Palomar Slides and Prints				121	2	6			
Other Slides and Prints				44	13	3			
Hire of Films				43	12	5			
British Astronomical Association				168	0	0			
London Mathematical Society				30	0	0			
Sundries				7	6	0			
							2,693	7	11
,, Royal Society Grant towards Expenses of Library							50	0	0
							7,172	0	2
,, Deficiency, one year to date							468	9	11
							£7,640	10	1

Balance Sheet

	£ s. d.	£ s. d.	£ s. d.
General Fund :—			
As at 1951 December 31	29,222 9 10		
Add W. H. Owston Bequest	880 12 5		
		30,103 2 3	
Less Excess of Expenditure over Income, 1952 ...		468 9 11	
			29,634 12 4
Trust Funds :—			
Capital as at 1951 December 31		7,459 10 2	
Income Balances at 1952 December 31		1,599 17 7	
Income Tax on Trust Funds, 1952 April–December, not yet refunded		20 12 6	
			9,080 0 3
Arthur Stanley Eddington Commemoration Fund :—			
As at 1951 December 31		534 2 6	
Income Balance at 1952 December 31		45 17 9	
			580 0 3
Reserves :—			
Repairs and Maintenance :			
As at 1951 December 31...	348 16 7		
Add Set aside 1952	300 0 0		
		648 16 7	
Sale of Discarded Books Fund :			
As at 1951 December 31...	213 6 4		
Add Sales, 1952	6 6 0		
Interest 1952	4 7 6		
		223 19 10	
			872 16 5
Composition Fees Reserve Fund :—			
As at 1951 December 31	2,403 10 2		
Received in 1952	242 11 0		
Special Donations	65 13 11		
		2,711 15 1	
Less 6 per cent transferred to Revenue Account ...		162 14 1	
			2,549 1 0
Staff Pension Fund :—			
As at 1951 December 31	675 17 10		
Add Interest for 1952	16 9 1		
		692 6 11	
Less Grant made in 1952		100 0 0	
			592 6 11
Benevolent Fund :—			
Balance at 1952 December 31			6 15 2
Amounts received in advance :—			
Contributions :			
1953 paid in 1951	9 9 0		
1953 paid in 1952	163 16 0		
1954 paid in 1952	5 16 0		
1955 paid in 1952	4 4 0		
		183 5 0	
Publications, 1953		216 10 5	
			399 15 5
Sundry Creditors for Accounts due but not presented (including provision for printing publications for 1952 and binding periodicals, not yet completed)			3,204 19 2
			£46,920 6 11

To the Fellows of THE ROYAL ASTRONOMICAL SOCIETY

We have examined the above Balance Sheet with the Books and Vouchers relating thereto explanations given to us.

We have verified the Securities representing the Investments and have found them to be

SUFFOLK HOUSE,
5 LAURENCE POUNTNEY HILL, LONDON, E.C. 4.
1953 June 1.

1952 *December* 31

	£	s.	d.	£	s.	d.
Investments :—						
General Fund, valued as at 1922 December 29 or subsequent cost...	30,489	17	6			
Trust Funds, valued at cost	7,548	2	2			
(Market Value 1952 December 31, £36,099 1s. 2d.)				38,037	19	8
Debtors :—						
General	308	17	2			
Income Tax Recoverable :						
General Fund	77	2	11			
Trust Funds	20	12	6			
				406	12	7
Deposits at Savings Banks :—						
General Fund	£6,383	3	5			
Trust Funds	982	2	7			
	7,365	6	0			
Balance on Current Account at Bank and Cash in Hand :—						
General Fund	357	5	10			
Trust Funds (including sales of Discarded Books Fund £44 1s. 11d.)	753	2	10			
	1,110	8	8			
				8,475	14	8
				£46,920	6	11

Note.—Contributions unpaid as at 1952 December 31, and amounting to £412 2s. 0d., have not been included in this Balance Sheet.

and certify it to be correctly drawn up therefrom and in accordance with the information and in order.

SHARP, PARSONS & CO.,
Chartered Accountants

INVESTMENTS

As at 1952 December 31

General Fund

£2000 Swansea Corporation 3½ per cent Stock.
£7386 12*s.* 9*d.* British Transport 3 per cent Guaranteed Stock, 1978/88.
£496 Consolidated 4 per cent Stock, 1957.
*£1035 Agricultural Mortgage Corporation, Ltd., 4½ per cent Debenture Stock, 1961–91.
£1000 Hull Corporation 4½ per cent Redeemable Stock, 1952–72.
£700 Birmingham Corporation 3 per cent Stock, 1947.
£2280 5*s.* 3*d.* War Loan 3½ per cent Inscribed Stock.
£1156 1*s.* 5*d.* Metropolitan Water 3 per cent " B " Stock.
£500 National Defence Loan, 1954–58, 3 per cent Registered Stock.
£500 Savings Bonds 2½ per cent, 1964/67.
£2118 3*s.* 5*d.* Savings Bonds 3 per cent, 1960/1970. (Holding " A ")
£695 16*s.* 0*d.* Conversion Loan 3½ per cent, 1961.
£2239 13*s.* 8*d.* Treasury 2½ per cent Stock, 1975.
£3050 13*s.* 0*d.* British Electricity 3 per cent Guaranteed Stock, 1968–73.
*£3718 British Gas 3 per cent Guaranteed Stock, 1990–95.
*£500 Commonwealth of Australia 3 per cent Loan, 1972–74.
£78 1*s.* 3*d.* War Loan 3½ per cent Registered Stock.
£2400 Defence Bonds 3 per cent (5th Issue).
*£3468 12*s.* 10*d.* Consolidated Stock 2½ per cent.
£880 Defence Bonds 3 per cent (5th issue).

Trust Funds

£1004 Consolidated 4 per cent Stock, 1957.
*£965 Agricultural Mortgage Corporation, Ltd., 4½ per cent Debenture Stock, 1961–91.
£491 10*s.* 0*d.* War Loan 3½ per cent Inscribed Stock.
£1160 16*s.* 3*d.* War Loan 3½ per cent Inscribed Stock.
£542 18*s.* 2*d.* Savings Bonds 3 per cent, 1960/1970. (Holding " B ")
£1122 19*s.* 6*d.* Savings Bonds 3 per cent, 1960/1970. (Holding " C ")
£1471 4*s.* 0*d.* Savings Bonds 3 per cent, 1955/1965.
£375 Savings Bonds 3 per cent 1955/1965.
£100 Savings Bonds 3 per cent 1960/1970. (Holding " D ")
£250 War Loan 3½ per cent Stock.
£100 Defence Bonds 3 per cent (5th Issue).

* *Taxed at source.*

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY

The John Lee Gift (1836 and 1844): In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were purchased by his heir, Edward Lee, Esq., for £700.

The Lawson Bequest (1856): Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

The Carrington Bequest (1876): R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2000 Consols.

The Lambert Bequest (1877): C. J. Lambert, Esq., presented to the Society the sum of £500 free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

The McClean Bequest (1905): Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2000, free of legacy duty.

The Farrar Bequest (1906): The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

The Parsons Gift (1922): The Hon. Sir Charles Parsons, K.C.B., F.R.S., gave to the Society £2500 War Stock 1929–47, in memory of his father, the 3rd Earl of Rosse, who made the 6-foot reflector, and who died 1876 October 31.

The Grove-Hills Bequest (1922): Colonel E. H. Grove-Hills, C.M.G., F.R.S., bequeathed to the Society, free of legacy duty, his collection of early astronomical and mathematical books up to the year 1700, together with a sum of £250 to cover the expenses incurred by the Society in connection with the books.

The Grove-Hills Fund (1922): In 1922 the Treasurer, Colonel Grove-Hills, collected by his private efforts, with the approval of the Council, a Special Fund to meet the immediate financial difficulties of the Society. The total amount received from all sources (including dividends on the investments representing the fund) has been £1913 1*s.* 11*d.*, of which £1480 2*s.* 10*d.* has been invested and is now represented by £535 Agricultural Mortgage 4½ per cent, £423 15*s.* 11*d.* War Stock 3½ per cent, and £695 16*s.* Conversion Loan 3½ per cent 1961.

The Lindemann Bequest (1931): A. F. Lindemann, Esq., bequeathed to the Society the sum of £1000, free of legacy duty.

The Archdeacon Potter Bequest (1933) (*see below*).

The Goodridge Bequest (1936): Captain J. J. L. Goodridge, who died 1936 March 13, bequeathed to the Society the sum of £50, free of legacy duty. In 1937 the bequest was invested in £49 0*s.* 4*d.* War Stock 3½ per cent.

The Herbert Spencer Bequest (1936): Herbert Spencer, Esq., who died in 1903, nominated the Royal Astronomical Society as one of twelve Learned Societies to be eventual beneficiaries of his residuary estate. His estate was wound up in 1936, and the Society's share of the residue amounted to £1241. The conditions of acceptance of the legacy were that the sum received should be spent in certain specified ways by the Governing Body within five years of the date of payment, and might not be used in any way for purposes of endowment. The bequest was finally expended during 1941.

The Lindley Bequest (1937): Miss Julia Lindley bequeathed to the Society the sum of £1000, free of legacy duty, which was received from the Public Trustee in the form of £1156 1*s*. 5*d*. Metropolitan Water 3 per cent " B " Stock.

The Stanley Williams Bequest (1939): A. Stanley Williams, Esq., who died 1938 November 21, bequeathed to the Society all his astronomical instruments, books, maps, photographs, manuscripts, etc., together with the sum of £200, free of legacy duty, for the reduction or publication of his observations of variable stars; and also a further sum of £100, free of legacy duty, for the furtherance of astronomy in general or of the Society in particular, in such manner as the Council of the Society may think fit.

The E. W. Brown Trust (1939) (*see below*).

The Plummer Bequest (1946) (*see below*).

The Carder-Davies Bequest (1948): D. Carder-Davies, Esq., bequeathed to the Society the sum of £3000, free of duty and without any condition, other than the expression of a wish that no part be spent on any purpose controlled or suggested by Government. The legacy has been invested in the following way: £1229 11*s*. in British Electricity 3 per cent Guaranteed Stock; £1779 9*s*. in Treasury 2½ per cent Stock, which have been added to the General Funds of the Society.

The M. A. Nadarov Bequest (1950) (*see below*).

The W. H. Owston Bequest (1951): William Henry Owston, Esq., who died 1950 December 15, after making some personal bequests, left the residue of his estate to the Society. The investments have been transferred to the Society and added to the General Funds. These investments comprised £3468 12*s*. 10*d*. in 2½ per cent Consolidated Stock and £663 2*s*. 6*d*. British Transport 3 per cent Guaranteed Stock, 1978/88. The estate was wound up in 1952 and the Society received a further £880 12*s*. 5*d*. in cash on 1952 May 14, which has been invested in 3 per cent Defence Bonds (fifth issue) and added to the General Funds.

SPECIAL FUNDS

The Archdeacon Potter Fund (1933): Archdeacon Beresford Potter, who died 1931 May 10, bequeathed to the Society a 3/88th share of his residuary estate. Part of this legacy received in 1933 now stands invested in £300

3½ per cent War Stock, the cash balance of £17 15*s.* 2*d.* having been expended on the library in 1934. A further £64 3*s.* 5*d.* received 1951 November 22 was invested in £78 1*s.* 3*d.* 3½ per cent War Stock. The Council resolved to allocate the dividends from this fund for the purposes of the library.

	£	*s.*	*d.*
1952 Jan. 1. Balance of Fund...	17	12	11
1952. Dividends, War Stock 3½ per cent	13	4	6
	£30	17	5

	£	*s.*	*d.*
1952. Purchase of Books ...	9	17	0
1952 Dec. 31. Balance of Fund	21	0	5
	£30	17	5

The Victor Nadarov Fund (1950): Mrs M. A. Nadarov bequeathed to the Society one-half of her residuary estate. The estate was wound up in 1950, and the Society's share amounted to £725 invested in Savings Bonds and War Stock. Under the terms of the legacy the Fund is to be devoted to the encouragement and promotion of the study of sunspots and is to be known as the Victor Nadarov Fund: subject to this condition, the Fund can be used, both as to principal and accumulated interest, in whatever way the Council considers most suitable. The money is invested in the following securities, which were transferred to the Society: £375 3 per cent Savings Bonds, 1955/1965; £100 3 per cent Savings Bonds 1960/1970; £250 3½ per cent War Stock. A further £100 (including £88 12*s.* 0*d.* income balance) was invested in 3 per cent Defence Bonds on 1951 February 9.

	£	*s.*	*d.*
1952 Jan. 1. Balance of Fund ...	148	19	7
1952. Dividend, 3½ per cent War Stock	8	15	0
Dividend 3 per cent Savings Bonds	14	5	0
Dividend 3 per cent Defence Bonds	3	0	0
Interest on London Savings Bank Deposit			10
	£175	0	5

	£	*s.*	*d.*	£	*s.*	*d.*
1952 Dec. 31. Balance of Fund:—						
In P.O. Savings Bank	£81	12	8			
In London Savings Bank	4	15	9			
In 3 per cent Defence Bonds ...	88	12	0			
				175	0	5
				£175	0	5

The Arthur Stanley Eddington Commemoration Fund (1948): The Council of the Society decided to commemorate the services to astronomy and to the Society of Sir Arthur Stanley Eddington, O.M., F.R.S., by instituting a gold medal to be known as the Eddington Medal. As the result of an appeal to all Fellows of the Society, a total sum was raised amounting to £534 2*s.* 6*d.* £400 of this sum was invested in 3 per cent Defence Bonds on 1951 February 2.

	£	*s.*	*d.*
1952 Jan. 1. Balance of Fund ...	164	5	2
Interest on Defence Bonds ...	12	0	0
Interest on London Savings Bank Deposit	3	15	1
	£180	0	3

	£	*s.*	*d.*	£	*s.*	*d.*
1952 Dec. 31. Balance of Fund :—						
In London Savings Bank	£156	17	3			
At Bank	23	3	0			
				180	0	3
				£180	0	3

The Benevolent Fund (1950): The family of the late Sir Frank Dyson, K.B.E., F.R.S., have assigned to the Society their share of the royalties received from the publishers of ***Eclipses of the Sun and Moon*** by Sir Frank Dyson and R. v. d. R. Woolley, to form the nucleus of a Benevolent Fund, to be used at the discretion of the Council.

	£	s.	d.		£	s.	d.
1952 Jan. 1. Balance of Fund:—	3	8	2	1952 Grants made	1	1	0
Donation received	3	1	0	1952 Dec. 31. Balance of Fund	6	15	2
Royalties received	1	7	0				
	£7	16	2		£7	16	2

TRUST FUNDS

The Lee and Janson Fund (1834 and 1879): In 1834 John Lee, Esq., LL.D., gave £100, and in 1879 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £309 16*s.* 3 per cent Savings Bonds, 1960/1970.

	£	s.	d.		£	s.	d.
1952 Jan. 1. Balance of Fund ...	86	2	8	1952 Dec. 31. Balance of Fund :—			
1952. Dividends, 3 per cent Savings Bonds	9	6	0	In P.O. Savings Bank £43 8 2			
Interest on P.O. Savings Bank Deposit	1	1	0	At Bank 53 1 6	96	9	8
	£96	9	8		£96	9	8

The Turnor Fund and the Horrocks Memorial Fund (1853 and 1876): In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £430 10*s.* 4*d.* 3 per cent Savings Bonds, 1960/1970. In 1876 the Society received a sum of £38 15*s.*, the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrocks: to this the Society added the sum of £55 15*s.*, and the whole now stands in £95 13*s.* 2*d.* 3 per cent Savings Bonds, 1960/1970. The interest on these funds is to be used in the purchase of books for the library.

	£	s.	d.		£	s.	d.
1952. Dividends, 3 per cent Savings Bonds	15	15	8	1952 Jan. 1. Balance of Fund (over-expended)	3	9	2
				1952. Purchase of Books ...	11	2	0
				1952 Dec. 31. Balance of Fund	1	4	6
	£15	15	8		£15	15	8

The Hannah Jackson (née Gwilt) Fund (1861): In 1861 Mrs Hannah Jackson (*née* Gwilt) gave £300 Consols, which now stands in £287 3 per cent Savings Bonds, 1960/1970 ; the interest to be given in medals or other awards in accordance with the terms of the Trust.

	£	s.	d.		£	s.	d.
1952 Jan. 1. Balance of Fund ...	31	4	3	1952 Dec. 31. Balance of Fund	39	16	3
1952. Dividends, 3 per cent Savings Bonds	8	12	0				
	£39	16	3		£39	16	3

The Harry Watson Memorial Fund (1923): In 1920 Mrs Watson presented to the Society the sum of £300 as a memorial to her late husband, Lieut.-Col. Harry James Watson, F.R.A.S., the interest on this sum to be used for the purchase of books for the library, such books to be indicated by a special book-plate. The gift now stands invested in £542 18*s.* 2*d.* 3 per cent Savings Bonds, 1960/1970. In 1923 Mrs Watson bequeathed a further sum of £958 17*s.* to the Society, which now stands invested in £965 Agricultural Mortgage 4½ per cent Stock. The Council resolved that these two sums should together constitute a Trust Fund, to be designated ***The Harry Watson Memorial Fund***, to be used for the purchase and binding of books.

	£	*s.*	*d.*		£	*s.*	*d.*
1952 Jan. 1. Balance of Fund ...	312	0	9	1952. Purchase of Books ...	96	5	1
1952. Dividends, Agricultural Mortgage 4½ per cent ...	22	16	0	1952 Dec. 31. Balance of Fund :— In P.O. Savings Bank £277 17 4			
Dividends, 3 per cent Savings Bonds	16	5	8	At Bank 4 8 0			
Income Tax, 1950 April–1951 April, refunded	20	12	6		282	5	4
Interest on P.O. Savings Bank Deposit	6	15	6				
	£378	10	5		£378	10	5

The George Darwin Lectureship Fund (1926): In 1926 Sir James Jeans presented to the Society the sum of £1000 for the endowment of an annual lectureship, to be called *The George Darwin Lectureship*, the lecture to be on some subject of interest to astronomers, preference being given, in electing a lecturer, to one normally resident outside the British Isles.

This sum now stands in £1004 Consolidated 4 per cent Loan. The income is annually applied to the purposes of the Trust in accordance with the terms of the Deed of Gift.

	£	*s.*	*d.*		£	*s.*	*d.*
1952 Jan 1. Balance of Fund ...	112	12	10	1952 Dec. 31. Balance of Fund :— In P.O. Savings Bank £154 5 7			
1952. Dividends, Consolidated 4 per cent Loan	40	3	2	At Bank .. 2 5 11			
Interest on P.O. Savings Bank Deposit	3	15	6		156	11	6
	£156	11	6		£156	11	6

The A. G. Stillhamer Trust (1937): A. G. Stillhamer, Esq., of Bloomington, Illinois, left all his property outright to Miss Maude S. Capps, of Bloomington; but on account of certain personal memoranda and conversation between Mr Stillhamer and Miss Capps, the latter resolved to carry out what she believed to have been Mr Stillhamer's wishes by the payment to the Royal Astronomical Society of the sum of 2500 dollars in cash, the conditions of acceptance being that the principal is to remain intact in the endowment fund of the Society, and the income therefrom to be used annually* to pay expenses of scientific research or to purchase definite scientific instruments for use in scientific

* Miss Capps, subsequently to the initial conditions of the Trust, agreed to the income not being expended annually.

instruction or research. The bequest has been invested in £491 10*s*. War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1952 Jan. 1. Balance of Fund ...	263	14	10	1952 Dec. 31. Balance of Fund :—			
1952. Dividends, War Stock 3½ per cent	17	4	0	In P.O. Savings Bank £116 5 4			
Interest on P.O. Savings Bank Deposit	2	16	6	At Bank 167 10 0			
					283	15	4
	£283	15	4		£283	15	4

The E. W. Brown Trust (1939): E. W. Brown, Esq., M.A., Sc.D., F.R.S., who died in 1938, bequeathed to the Society the sum of five thousand dollars, and desired that the income from the bequest should be used for assistance in the calculation of accurate orbits of the bodies of the solar system, such income as should not be used for this purpose being used for the general purposes of the Society. The bequest was received in 1939 July, and was invested in £1160 16*s*. 3*d*. War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1952 Jan. 1. Balance of Fund :	298	8	3	1952 Dec. 31. Balance of Fund :—			
1952. Dividends, War Stock 3½ per cent	40	12	6	In P.O. Savings Bank £205 12 6			
Interest on P.O. Savings Bank Deposit	5	0	6	At Bank 138 8 9			
					344	1	3
	£344	1	3		£344	1	3

The Plummer Bequest (1946): H. C. Plummer, Esq., M.A., F.R.S., bequeathed to the Society the sum of £1000, to be invested and treated as a Trust Fund, the income to be at the disposal of the Council for all purposes, with a recommendation that they should consider the possibility from time to time of helping the Norman Lockyer Observatory. The Society was also named as one of the residuary legatees. In 1947 October, a first distribution, under the terms of the will, of £1500 was received from the Administrators of the Estate, which has been invested in £1471 4*s*. 0*d*. 3 per cent Savings Bonds, 1955/1965; this sum and any subsequent sum or sums which may be received from the Administrators will be used in accordance with the late Professor Plummer's wishes.

	£	s.	d.		£	s.	d.
1952 Jan. 1. Balance of Fund ...	176	10	8	1952 Dec. 31. Balance of Fund	220	13	4
1952. Dividends, 3 per cent Savings Bonds	44	2	8				
	£220	13	4		£220	13	4

LIST OF PUBLIC INSTITUTIONS AND OF PERSONS WHO HAVE PRESENTED GIFTS (OTHER THAN BY EXCHANGE) TO THE LIBRARY DURING THE YEAR 1952

Academy of Sciences, U.S.S.R.
Argonne National Laboratory
Armagh Observatory
Association Française d'Observateurs d'Etoiles Variables
Association of Special Libraries and Information Bureaux
Astronomical Society of the Pacific
Astronomical Society of South Africa
Astronomical Society of Tasmania

Astronomische Gesellschaft
Bamberg, Institut für Erdmessung
Berne, Astronomisches Institut der Universität
British Astronomical Association, N.S.W. Branch
British Interplanetary Society
British Society for the History of Science
Buenos Aires, Servicio Meteorologico Nacional
Centre National de la Recherche Scientifique, Paris
Danske Amatørastronomers Organ
Deutsche Akademie der Wissenschaften
English Universities Press Limited
Faber and Faber Limited
Goethe Link Observatory
Göttingen University
Griffith Observatory, Los Angeles
Hamburg Observatory
Harvard College Observatory
Imperial Chemical Industries Limited
International Astronomical Union
International Council of Scientific Unions
International Union of Geodesy and Geophysics
Jeremiah Horrocks Observatory, Preston
Liège, Institut d'Astrophysique de l'Université
Lowell Observatory
Maria Mitchell Association
National Bureau of Standards, Washington
National Oceanographic Council
The Editors of *The Observatory*
Oporto, Faculdade de Sciências
Oxford University Press
Prague, National Observatory
Radar Research and Development Establishment
The Editors of *Říše Hvězd*
Santiago (Spain), Observatorio
Service de Prévision Ionosphérique Militaire
Sociedad Astronomica de Mexico
South African Association for the Advancement of Science
Taylor and Francis Limited
Trieste, Istituto Talassografico
Union Radio Scientifique Internationale
World Calendar Association Inc.

Mr R. M. Baum
Dr F. Becker
Mr E. A. Beet
Mr G. van den Bergh
The British Astronomical Association
Dr J. A. Clegg
The late Dr W. Hall
Dr A. Hunter
Mr M. Lavallois
Professor A. C. B. Lovell
Professor H. Mineur
Professor S. A. Mitchell
The late Mr A. H. Phayre
Dr J. G. Porter
Mr C. A. Swindin
Mr F. Twyman
Dr G. de Vaucouleurs
Dr G. J. Whitrow

OBITUARY NOTICES

CHARLES PRITCHARD BUTLER, son of Charles Butler, cutler and wood carver, and of Elizabeth Pritchard, was born in Sheffield on 1871 August 19 and died in Cambridge 1952 November 21.

He was educated at the Central School and Firth College, Sheffield, where he was awarded the Lancastrian Scholarship, and at the Royal College of Science, London, of which he was an Associate. He had originally planned a career in medicine but changed his plans during his student days.

He was appointed a computer by the Solar Physics Committee in 1898, working under Sir Norman Lockyer; in 1902 he became Second Assistant at the Solar Physics Observatory at South Kensington. He moved with the Observatory to Cambridge where he was placed, as a Senior Observer, in charge of the work of the spectroheliograph. At the time of the move, 1913, Butler was actually in India, acting as Director of the Kodaikanal Observatory during the interregnum between the Directorships of Michie Smith and Evershed. He retired from his Observatory post in 1937.

He published several papers in the *Monthly Notices* on an eruptive prominence, on the distribution and life history of solar calcium flocculi and on variations in the spectrum of Nova Aquilae, 1918. He was a member of expeditions to observe three total solar eclipses, 1905 in Spain, 1914 in the Crimea and 1927 in Norway. He was probably the first to isolate in a laboratory spectrum of a helium tube the line 4686 A of He II, though this was before its identification was established. He served for many years on the Council of the British Astronomical Association as Director of the Solar Section.

He was elected a Fellow of the Society on 1908 November 13.

F. J. M. STRATTON.

LESLIE JOHN COMRIE died on 1950 December 11, the Society thereby losing an outstanding individualist who was always wholeheartedly devoted to its interests, and wholeheartedly devoted to certain aspects of astronomy. It would be an untruth to say that Comrie was wholeheartedly devoted to astronomy in the general sense; his devotion was, in the nature of the man, limited to that part of our science in which he was himself interested. This excluded most of what we call astrophysics, which was perhaps his *bête noire*. On one occasion he remarked with characteristic sarcasm that he supposed that in future we should no longer have an Astronomer Royal but an "Astrophysicist Royal". But there was no doubt about his devotion to positional astronomy; when Comrie gave his allegiance he gave it completely, and, let it be said, often fanatically. He was apt to have no interest in anything unless he could devote himself to it with something like fanaticism, with the result that his range of interests was such that if he had been a normal man he would have been called "narrow". But he was not a normal man; paradoxically enough, his "narrowness" made him completely lovable to those who really understood him. A colleague once told him that he was a fanatic; Comrie regarded this as a high compliment. And there can be no doubt about what astronomers owe to his fanaticism; they are indebted to him for the complete revision and revolutionary

improvement of the *Nautical Almanac*, an achievement which can perhaps be regarded as his *magnum opus*. Many of his friends have regretted that his later career did not follow the established order of things, according to which he would have remained a respected Superintendent of the *Nautical Almanac*, adding further improvements to the offspring of his brain, and in due course retiring with honour when the time came for him to relinquish control of the Office. But it was not to be, and, as far as the interests of Science in general and Astronomy in particular are concerned, need we really regret this? His main contribution to the *Almanac* was done, its future development was assured in the hands of the competent successor whom he himself had trained, and it naturally happened that his successor's individuality had its effect on the Nautical Almanac Office and secured improvements which Comrie himself could hardly have effected (but it is most unlikely that he would have agreed with this). For the *Almanac* the change produced good results, and for Comrie there was other work to be done and other services to Science to be rendered.

Some reference to the circumstances which led to the severance of Comrie's connection with H.M. Nautical Almanac Office will serve to give insight into his character. The plain fact is that the severance was inevitable. He was, as has been indicated, a rather fanatical individualist, and for such the British Civil Service (admittedly to its occasional detriment) is apt to provide a round hole for a square peg. Comrie was appointed to the Office on 1925 October 30 with the grade of Assistant, and four months later, on 1926 March 4, he became Deputy Superintendent with a practical assurance of further early promotion, since the Superintendent, P. H. Cowell, had only a few years longer to serve. The Office at that time was almost static. Cowell had planned the routine work of preparation of the two almanacs (the standard and abridged editions) with superlative skill, with highly trained arithmeticians and the use of logarithms in mind; moreover he had gradually allowed the permanent staff to be replaced by outside workers, generally retired members of the staff. This organization worked efficiently and with little necessity for detailed supervision; but it clearly could not be continued for more than a few years. There were no facilities for training new staff, and there were immense difficulties in introducing new ideas into the almanacs and new methods of computation. To Comrie, overflowing both with original ideas in computational astronomy and with the necessary energy and drive to put them into operation, the organization was totally unsuitable. Whilst Deputy Superintendent he directed his efforts to the introduction and development of the new mechanical methods of computation. At the same time he was brought to realize the need for building up a staff suitable for the fulfilment of the wider international responsibilities of the Office and for the application of the new methods. On his promotion to Superintendent on 1930 August 8 (Cowell retired on August 7) he at once applied himself to this task, and it was at this point that friction developed with administrative authority.

This friction arose as a result of Comrie's personality. A wholehearted enthusiast himself, he failed to realize that some, at any rate, of his administrative superiors, who were accustomed to the peaceful conduct of the affairs of the Office under Cowell, needed to be convinced of the need for change. It must be said that Comrie was apt to find it somewhat difficult to understand the point of view of others, and he would certainly have misinterpreted the natural caution and deliberation with which his proposals were received. A more

tactful man would probably have secured without too long a delay the required official blessing for action which was certainly necessary, but to Comrie the circumstance that he did not get immediate response on a level with his own enthusiasm indicated what he would characterize as administrative sloth and incompetence; and, what was worse, we may well surmise that this characteristically blunt man did not hesitate to say so. This would certainly not go down well at the Admiralty. But it must not be thought that the British Civil Service does not appreciate a good man when it gets him. Comrie's work and ideas were certainly assessed at their true value by many, but he had an unfortunate knack of occasionally antagonizing those who were prepared to back him.

To understand how this came about we must try to appreciate his mental make-up, which was a paradoxical mixture of simplicity and complexity. On the one hand he could be really extraordinarily naïve and he would sometimes handle a situation calling for tact and finesse with a deplorably blunt and tactless approach. But he was also a very proud sensitive man who had a strong tendency to suspicion, and he would often, quite unjustly, attribute to others a desire to block his activities or to do him an injury in some way or the other. This trait of suspicion was probably psychologically connected with his deafness, which increased rapidly as he grew older, and with his physical incapacity (he lost a leg in the First World War while serving in France with the New Zealand Expeditionary Force). At any rate it seems to have led him, on occasion, to adopt a complicated and tortuous procedure, when a frank and straightforward attitude might well have got him all he wanted. We may well surmise that some of his superiors, who would otherwise have supported him, were antagonized by being made to feel that they were not being treated with the frank confidence to which they were undoubtedly entitled. The disagreement between Comrie and the Admiralty on the running of H.M. Nautical Almanac Office finally brought his appointment to an end in 1936 August.

Comrie was born at Pukekoke, New Zealand, on 1893 August 15. He was trained as a chemist, taking his M.A. at Auckland University in 1916 with Honours in Chemistry. In spite of his deafness, he served with the New Zealand Expeditionary Force in the First World War and, as has been recorded above, was wounded, losing a leg. At the end of the War he did not return to Chemistry but forsook it for Astronomy and Computation, subjects in which he had become interested at Auckland University. He proceeded to St. John's College, Cambridge, as a research student, and in 1920 he was elected to an Isaac Newton Studentship. He was awarded the degree of Doctor of Philosophy in 1923, the main part of his thesis consisting of a very thorough investigation of the occultations of stars by planets. This thesis has, unfortunately, never been published; it contained a complete historical account of the subject and a detailed study of the best methods of predicting these phenomena. The work led to a revival of interest in observations of planetary occultations, a revival which was welcomed by Eddington in his Presidential Address, delivered on 1922 May 30, on the occasion of the Society's Centenary Celebration (*M.N.*, **82,** 434). It was at this period of Comrie's career that the Computing Section of the British Astronomical Association was formed in 1920, and Comrie was appointed its first Director. The way in which this Section has devoted itself to what Comrie called in the first Report of the Section "the realms of computational astronomy"

is well known, and needs no comment here beyond the obvious one that the well-deserved prestige of the Section is in no small measure due to the stimulating enthusiasm of its first Director.

While Comrie was at Cambridge it was arranged that two Isaac Newton students (himself and the present writer) should each spend two months working at the Royal Observatory, Greenwich. Comrie went first and I followed immediately after. On arrival I was given to understand that I had come to learn and not to teach Greenwich its job. The fact was that Comrie did not approve of the computing methods then in use, and with characteristic reforming zeal and bluntness had told Sir Frank Dyson (then Astronomer Royal) what ought to be done. This was not too well received, but I think I ought to add that there is another side to the incident : Comrie's advice was, in my opinion, sound.

In these early years of his career Comrie had already developed the sound genius for computational science which eventually led him to do great work, and he had already formed the blunt approach which was eventually fated to create hostility and to hinder the advancement of his plans, good though the latter nearly always were. He proceeded from Cambridge to the United States, where he spent three years, teaching Astronomy and introducing Computational Science into the undergraduate course, first at Swarthmore College, and then at North Western University, Evanston, Illinois. The reputation which he had earned in his own field then led to his appointment to H.M. Nautical Almanac Office in 1925. His career at the Office has already been sketched, but we must now dwell on the technical details of his achievements there. D. H. Sadler writes as follows :—

" It was not long after Comrie's appointment that his experience of computing and table-making was felt on the work of the Office and the design of the almanacs. The *Nautical Almanac, Abridged for the use of Seamen*, introduced in 1914 as a result of consultation with the Society, had only partially surmounted in the editions for 1925 to 1928 the effects of the change from noon to midnight in the origin of measurement of mean time; Comrie redesigned it for 1929 as much as he was allowed to do, introducing the quantities E (12^h *minus* equation of time) and R (sidereal time *minus* mean time) which have remained as standard concepts ever since. This was, however, a trivial undertaking compared with the complete revision of the *Nautical Almanac* for 1931 which followed. Until 1930 the Almanac had retained the general form and arrangement introduced at the instigation of the Society in 1834, after long opposition to change from Thomas Young, then Superintendent. The chief factors that made a change desirable after nearly a hundred years were the separation of the navigational ephemeris from the astronomical ephemeris and the growing impact of modern computing methods. It is unnecessary here to give the changes in detail; their effect is evident in the present almanac. The very considerable task of revision was carried through almost single-handed, with the greatest attention to every detail of presentation and typography.

" In the Almanac for 1931 there were introduced ephemerides for the standard equinox of 1950·0, a direct consequence of Comrie's paper on ' The Use of a Standard Equinox in Astronomy ' (*M.N.*, **86,** 618, 1926). This may well prove to be his most lasting contribution to Astronomy, coupled as it was with the preparation and publication of the volumes of *Planetary Co-ordinates*

referred to the Equinox 1950·0 and an enormous simplification in the computation of special perturbations.

" During this period, Comrie was actively engaged in the application of commercial calculating machines to scientific computing, and he introduced modern calculating machines into the Office, gradually changing the methods of computation. In particular, he found the routine summation of the periodic terms in Brown's *Tables of the Motion of the Moon* unduly laborious by hand, and he brilliantly applied Hollerith tabulating machines to their summation; in the course of a single year he had most of the entries in Brown's Tables punched and produced the ' sums ' of the various groups, many of them up to the year 2000. He was prevented from completing the whole work only by the inability to extend, for a short time, the hire of the machines. This work, which is fully described in *M.N.*, **92,** 694, 1932, represents one of the earliest applications of punched-card machines to scientific computation; he used the same method for evaluating the nutation and, later, for the lunar perturbations of the Earth.

" About the same time he installed in the Office a Class II Burroughs machine for which he developed the continuous methods of subtabulation using a ' bridging ' second difference. Under Comrie's direction this machine turned out tables, generally by subtabulation from already known values, at an incredible rate. He had earlier produced the new edition of Barlow's Tables, the computer's indispensable companion, and had collaborated with L. M. Milne-Thomson in the authorship of the *Standard Four-Figure Mathematical Tables*. Arising from a conversation with Professor J. Peters (of the Astronomisches Rechen-Institut and the foremost table-maker of his day) at the 1930 meeting of the Astronomisches Gesellschaft in Budapest, Comrie and Peters embarked on the enormous project of preparing tables of the natural trigonometrical functions for every second of arc. The original plan had to be modified several times, always being reduced as the difficulties of publication became apparent; it finally gave rise to two distinct tables of the four functions sin, cos, tan and cot, one to seven and the other to eight figures. Generally, Peters supplied the pivotal values and the differences to many figures, and Comrie interpolated them and made copy; in all nearly ten million values were produced on the Burroughs machine for this project alone. In 1939 Peters succeeded in getting the *Achtstellige Tafeln* published in Germany by Reichsamt für Landesaufnahme; this table has been photographically reprinted several times in this country and in the U.S.A. No publisher nor financial support has been forthcoming in this country for the 7-figure table, the copy for which is now being placed in the Royal Society depository of unpublished mathematical tables.

" Much of the above work had been started while Comrie was still Deputy Superintendent; on Cowell's retirement in 1930, Comrie was his natural successor. As Superintendent he intensified his campaign for the increased use of modern calculating machines and methods of computation, both in the Office and elsewhere; his greatest triumph in this field was the ' discovery ' of the National Accounting Machine (then the Ellis machine) and its application to scientific computation. These machines have proved invaluable to the Office during the past 16 years. It is not too much to say that during this period Comrie laid the foundations for the recent revolution in computing

practice, and that his work then will continue to influence future developments. He was not content to apply commercial machines to astronomical computation; he developed powerful new methods for use with the machines, particularly in the field of interpolation and subtabulation. The interpolation tables and explanation in the *Nautical Almanac* for 1937, which were reprinted for separate sale as *Interpolation and Allied Tables*, were merely the last of several original contributions. During most of the time he was in the Office, Comrie was the energetic secretary of the British Association Mathematical Tables Committee, which owed much to him for the design and typography of its justly acclaimed tables, as well as for a large proportion of the actual computation.

" Comrie's astronomical interests were primarily in the calculation of the phenomena of eclipses and occultations, for Sun, Moon and planets, following the post-graduate work he did at Cambridge. He had been largely instrumental in founding the Computing Section of the British Astronomical Association, partly so that it could deal with work outside the formal scope of the Office; and much of his work on occultations and the phenomena of Jupiter's and Saturn's satellites was done for the B.A.A., or in conjunction with the Computing Section. He produced the first B.A.A. *Handbook*, and was always generous with help and advice to the Section. In the course of this work he came into contact with J. D. McNeile, who had constructed in wood a machine for the prediction of occultations by the Moon. Comrie borrowed the machine for use in the Office and inaugurated a greatly enhanced programme of centralized occultation prediction; McNeile's machine was copied in metal by A. C. S. Wescott in the Royal Observatory workshop, and was used as a basis for the prediction of occultations in all parts of the world. To simplify the reduction of observations he devised the ' Occultation Reduction Elements ' first published for 1937. He also adapted Chauvenet's classical formulae for solar eclipses to machines, and completely revised the data in the Almanac concerning Saturn's satellites to allow for the prediction of their eclipse, occultation, transit and shadow transit.

" He was an active member of the International Astronomical Union and attended all the meetings from 1928 onwards, being President of Commission 4 (Ephemerides) from 1932 to 1938. At the 1932 meeting he raised the question of the duplication of publication of apparent places of stars and suggested an international volume ; this led in due course to the appearance of *Apparent Places of Fundamental Stars* and to the more efficient redistribution of astronomical calculations and publication.

" Comrie was not, and did not claim to be, a mathematician; but he possessed two great qualities that enabled him to tackle and solve problems in a practical way. Firstly he had the necessary clarity of mind to see a computing problem in its entirety, and secondly he had the courage and the energy to attack it directly. His work is characterized by an essential simplicity of approach, supplemented by an impeccable computing technique in which the greatest attention is paid to detail. Results are not obtained in this way through flashes of brilliance; they are always the outcome of steady work, in which every alternative is examined and every step tested. His energy and application were alike remarkable; the work he did in his ten years in H.M. Nautical Almanac Office is staggering in its sheer magnitude—at least, to those who can appreciate the amount of detailed work involved in the planning of a complicated piece of

computation or the typographical lay-out of a page of figures. A week-end for him often meant 18 hours' solid uninterrupted work."

The characteristics, which made Comrie one of the greatest Superintendents of H.M. Nautical Almanac Office (perhaps the greatest) as far as the technical side of its work is concerned, served him well in his subsequent career and gave his firm, Scientific Computing Service Limited, its well-deserved high reputation. This firm, which was founded by Comrie in 1937, was the first professional organization (and still the only one) to provide large-scale computation with high mathematical content. Under Comrie's leadership a powerful and experienced team was built up and major computational operations have been performed for Government Departments, for Universities and for Industry. Comrie was particularly proud, and justifiably so, of the war work of his firm.

Three hours after war was declared he was approached by the War Office who required, as a matter of urgency, some ballistic tables. The work was planned and begun within 24 hours and two volumes of 200 pages of double entry tables were computed, set, printed, indexed and bound, all in the first twelve days of the war. This characteristic display of drive combined with skill was followed, over a year later, by the successful solution of a difficult but important problem. During the winter of 1940–41 the enemy was using beam wireless stations on the north coast of France to guide his raiders, and it became important to locate the position of one of these. The available very incomplete and very imperfect data were supplied to Comrie's firm, bit by bit, after each raid. After several months' intensive work on a difficult inverse problem, rendered all the more difficult by incomplete data, an estimate of position was reached, and immediate air reconnaissance revealed the station, well camouflaged, within 100 yards of the estimate. This work was followed by the construction of a series of " wind graphs " for facilitating sound ranging. Later on the firm produced certain bombing tables and undertook the heavy task of converting 24 000 latitudes and longitudes from the Prussian Triangulation to the rectangular coordinate system used for artillery purposes.

Truly Comrie served his country well, and astronomers will be particularly interested in the results which followed as a consequence of experience developed in an astronomical institution. In the operations of his firm major emphasis was always laid on accuracy. He, the founder, was naturally during his active life the mainspring which operated the whole mechanism, but he did not forget the task of training others who would carry on his methods.

His main work was always in the application of commercial machines to computational problems and in the construction of mathematical tables. He was especially interested in table-making, and some of his activities in this field have already been mentioned. He always believed that the maker of tables not only should, but also could, provide tables that were substantially free from errors, and the tables bearing his name have set up a standard which can hardly be surpassed. But this was not all : he believed that it was his duty to give the user of tables every possible convenience, so not only were his tables checked and re-checked, but they were designed to be easy to interpolate and easy to read. This last is a much-to-be-desired characteristic which has not always been realized in the past. But Comrie had an expert knowledge of typography and he applied this knowledge, together with unrivalled experience and tireless

attention to detail, to achieve something like perfection in presentation as well as perfection in accuracy. This feature of his published tables is one which has been appreciated to the full by users afflicted with defective eyesight; often such users by reason of their lack of typographical knowledge do not realize *how* the end has been achieved, but they well know that it has been achieved and that the use of Comrie's tables involves the minimum of eyestrain. And apart from the tables bearing his own name, Comrie, in his capacity as Secretary of the British Association Mathematical Tables Committee, saw to it that the B.A. Mathematical Tables came up to his standard of presentation. During the last two years of his life he was a member of the Royal Society Committee on Mathematical Tables. His services on such committees were always of the highest value but it must be recorded that at times, at any rate in his earlier years, the proceedings were apt to engender heat.

Comrie's expert knowledge of typography was of considerable value to the Society when the general style of printing of our *Monthly Notices* was changed. The changes were worked out by a sub-committee of Council of which he was a member, and the new style, which commenced with Volume **92** (1931–32), was largely due to him. But he was annoyed because *all* his ideas were not accepted by Council, and he remarked with characteristic impatient petulance to the present writer: " Then I am finished with the R.A.S." Of course he did not really mean that; he was too devoted to the Society to mean it. He was subsequently persuaded that his efforts were really appreciated by the Society.

He had previously rendered a service to the Society of quite another kind, although his activity in its interests was not wholly appreciated at the time. A state of affairs had developed in which the Council had to a large extent become a closed caucus; there was no rule whereby members of Council retired in rotation, as they do now, and several members of Council had, by 1927, served continuously for many years. At the Annual General Meeting held on 1927 February 11, Comrie, ever a stormy petrel, proposed (acting in conjunction with the late Mr Frank Robbins) some new members of Council as alternatives to the Council nominees. In the end the Council nominees were elected on the ballot, but the protest was effective; members of Council realized that all was not well, and the much-needed reform followed shortly afterwards.

But we must return to Comrie's activities in the field of mathematical tables. He not only made new tables of a standard which had never before been attempted, but he had a profound knowledge of existing ones. He was the author of a comprehensive note on Mathematical Tables which appeared in *Monthly Notices* for 1932 February. For many years he hoped that some day he would be able to produce an index covering all existing tables. Such an index is now available, but Comrie is not its author, although he played an important part in its final production. The following extracts from the Publisher's Preface to *An Index of Mathematical Tables* by Fletcher, Miller and Rosenhead, published in 1946 by Scientific Computing Service Limited, tell the story in Comrie's own words and illustrate the generosity which was a prominent feature of his character.

" My interest was naturally aroused when I learned that the three authors of this Index were working on a subject dear to my own heart—one on which I have laboured for a quarter of a century. I realised immediately that, with their combined mathematical knowledge, their team work, and the opportunities

for research that come a little more easily in universities than to one responsible for a team of thirty computers busily engaged on war work, they had the means of bringing to early fruition what might take me a decade. I therefore resolved to offer every assistance in my power. Of the nature of that assistance the authors themselves have spoken in generous terms. It consisted mainly in seeing that the standard of printing was up to the standard of authorship. Photographic reproduction of typescript was rejected from the beginning, and a four-figure bill for typesetting faced without hesitation.

" Should there be found any who complain about the price of this book, let them be informed that the price of any book is a function (although not a tabulated one to be found in this *Index*) of the cost of production and of the estimated sales. Here the former is high, and the latter, from the specialised nature of the subject, cannot be expected to be high. Indeed the publisher faces no prospects other than financial loss, which he does calmly with the knowledge that he has served science by helping this work to see the light of day in its present dignified form."

As a matter of fact Comrie's own projects went rather further than the compilation of this very valuable *Index*. For many years he had conducted systematic and thorough searches for errors in existing tables, and he worked up to the end at this task, which he almost completed. It is good to learn that the results of his labours will appear as part of a new edition of the *Index*.

Before the publication of the *Index* Comrie had begun what was fated to be his last contribution to serious table-making. In 1944, the centenary of the first publication of *Chambers's Mathematical Tables*, the publishers, Messrs. W. & R. Chambers Ltd., had asked Comrie to report on these tables with a view to bringing them thoroughly abreast of modern requirements. Report on them he did, and his report must have been something of a shock to the publishers. The existing seven-figure tables were characterized by the difficulty of interpolation necessarily inherent in a single volume of modest dimensions (and so of modest price). Comrie was never the man to mince matters; the details of his report and of his subsequent conversations with the firm are not known, but anyone who knew him may well make some surmises. He probably said that the existing tables should be consigned to a bonfire, or words to that effect, and he probably pointed out with considerable emphasis, backed by his unrivalled experience, that there were already some excellent (and bulky) seven-figure tables in existence, but that there was a definite need for six-figure ones. The essential point however in the conversations that took place between Comrie and Messrs Chambers is that the latter were not slow to realize that they were dealing with a man who knew what he was talking about; at any rate his report was accepted, and he was commissioned to prepare the new *Chambers's Six-Figure Mathematical Tables*. The main tables comprise two volumes, one giving logarithmic and the other natural values; there is also an Abridged Edition which combines the most important tables in the two volumes; and in addition there are two sets of four-figure tables. But no serious computer can afford to be without the two main volumes, concerning which Comrie remarked in the preface that they " may fairly be described as one of the greatest of all British table-making enterprises ". It is characteristic of Comrie that he himself should have made this remark, which will be endorsed by many users. These tables exhibit all his skill in presentation as well as his high standard of accuracy. The

following extract from the preface is quoted as being typical of the author who, it will be noted, deliberately refrained from correcting a few known but immaterial errors.

" Proofs have been read against a great variety of published tables where appropriate ones exist. Where the tables are the result of original calculations, no undue steps have been taken to secure rigorous accuracy of half a unit in the last decimal. In no case should any error greater than +0·52 units of the last decimal be found. Moreover, it is confidently believed that the cases where the error exceeds +0·51 units of the last decimal could be counted on the fingers of one hand; those that are known to exist form an uncomfortable trap for any would-be plagiarist."

It should be added that the " Explanations " to these volumes are of high value in themselves and, as has been remarked by Miller (*Nature*, **167**, 14), they may also be used as a textbook on general computational techniques. A very large proportion of Comrie's computational experience has been compressed into these " Explanations ".

His contributions to table-making and computational technique represent a very substantial service to Science which was recognized by his election to Fellowship of the Royal Society in 1950 March. This election gave him great pleasure at a time when he was depressed by rapidly deteriorating health. He had been afflicted by a stroke which left him with an active mind, but which impaired his speech and left him with a reduced capacity for work. This made him definitely unhappy; the trouble was that he had practically no interests apart from his work. Actually he did work, right up to the last, but by the autumn of 1950 it had become apparent to some of his friends, and probably to himself, that the end was drawing near. On Friday, December 8, he attended the dinner of the Royal Astronomical Society Club, an institution to which he was greatly attached. He very obviously enjoyed the evening and the good companionship which is a feature of these dinners, but he seemed to think that it would be the last meeting of the Club for him. On the following morning (Saturday) he went with the present writer for a walk in Greenwich Park; he was then depressed, and it was apparent from his conversation that his will to live was vanishing. The end followed swiftly; he died in his sleep on the Sunday night as a result of another stroke.

A brief reference has already been made to his generosity. A circumstance can now be disclosed which, so far, has been known only to Officers of the Society and to its office staff. For some years Comrie paid an additional subscription to the Society and asked that it should be used to continue the Fellowship of someone who would otherwise have to resign for financial reasons. This was but one typical instance out of many. Allied to his generosity was his hospitality; in particular he took great delight in entertaining visiting astronomers, and not many such came to London without visiting his house in Blackheath.

He was a man who lived for precision in all things, and not merely in all important things. Indeed, the trouble he would take over some matters appeared to his friends as verging on the ludicrous. I well remember the care with which he would weigh out with a balance the exact amount of salt prescribed for the routine " rejuvenation " of a water softener he had installed in his house. But this was typical of the man; he lived for precision, and being prepared to go to

extreme pains to achieve it, he was apt to be intolerant of others who would not take even a fraction of the trouble he took himself. It was perhaps this unduly critical attitude, generally well justified factually, which led to some difficult personal relationships. His own standards were so high that he must often have been disappointed in the casual reception accorded to work on which he had devoted so much time and thought. His thoroughness in everything he did was well illustrated by the help and encouragement he so generously gave to all, particularly amateur astronomers, with computational problems. Like others he occasionally found his efforts rewarded with what appeared to him as ingratitude, and when this happened it hurt him very very much. He was a formidable opponent and a staunch friend. He was quick to quarrel, but ready to make it up—provided the other fellow made the first approach. Proud, sensitive, apt to be suspicious, patient in enduring severe physical handicaps, sometimes very impatient in smaller matters, often childishly simple and naïve, on occasions unbelievably tortuous, generous (often to the verge of quixotism), sometimes a hard bargainer, lovable, but at times oh! so exasperating, tactless, and blunt, and above all outstandingly competent in his own field (to the exclusion of normal interests) and painstakingly thorough in all things, Comrie's personality has been indelibly printed on the memories of those who knew him ; and he has left his own memorial in his great services to Computational Science, in his revision of the *Nautical Almanac*, and in the firm which he founded.

He was twice married; firstly, in 1920, to Noeline Dagger of New Zealand, and secondly, in 1933, to Phyllis Betty, daughter of the late H. D. Kitto of Whiteshill, Stroud, Gloucestershire (and sister-in-law to the present writer). There is one surviving son of the first marriage and one of the second.

He was elected a Fellow of the Society on 1919 December 12 and served on the Council from 1929 February 8 to 1933 February 10.

In preparing this Obituary Notice of a man with whom I, like others, have quarrelled, made it up, and learned to love and respect, I am indebted to Mr D. H. Sadler for the passage quoted. Mr Sadler has also supplied a description of H.M. Nautical Almanac Office at the time that " L.J.C. " (as Comrie was designated among his friends and colleagues) joined it. I have drawn freely on other Obituary Notices and in particular on those of J. C. P. Miller (*Nature*, **167,** 14, 1951 January 6) and by J. G. Porter (*Journal B.A.A.*, **61,** 132, 1951 April). The information given of the war work of Scientific Computing Service Limited is extracted from a booklet issued in 1950 by the firm.

W. M. H. GREAVES.

PETER DOIG, for many years Editor of the *Journal of the British Astronomical Association*, died on 1952 October 13 after a painful illness. He was born in Glasgow in 1882, and served his apprenticeship as a draughtsman with the Clydebank firm of John Brown. His subsequent experience in America and at Belfast led to an appointment in Shanghai, and it was here that he suffered that serious illness which was to leave him with a painful physical disability. Returning to England in 1918, he was appointed General Secretary of the Association of Engineering and Shipbuilding Draughtsmen, and continued in this post until 1945. His last years were clouded with many periods of illness, but he continued with his editorial duties almost until the end. He is survived by his widow and a married daughter.

Doig's early interests in astronomy became apparent after the first World War, and he was elected a Fellow of the Society in 1922. He served on the Council of the British Astronomical Association at various times in the years 1921 to 1929, and in 1930, on the retirement of Mrs Maunder, he became Editor of the Association's *Journal*. In this capacity he served for two periods from 1930 to 1937 and from 1947 until his death, and was also Vice-President in the years 1937–1939.

The high standard which the *B.A.A. Journal* maintained during these years was due in no small measure to Doig. It was an open secret that he wrote most of the " Notes " which gave his readers a sound appreciation of the advances made in astronomical research. His own knowledge of the subject was extraordinarily wide, yet throughout his life his main interest was always stellar astronomy. In the early years of his astronomical work he collaborated with other well-known astronomers in writing *Splendour of the Heavens*—a book which is almost a classic, and is still in great demand. His own contribution, two chapters on stars and on the scale of the Universe, was expanded later in his book *Outline of Stellar Astronomy*, a second edition of which appeared in 1947. There was always a spirit of orderly neatness in everything that he wrote—an obvious reflection of his logical mind—and this was very clearly displayed in his *Concise History of Astronomy*, which appeared in 1950. Before his last illness he was able to complete the correction of the proofs of some 100 pages which he had written for the new *Astronomy for Everyman*.

Doig's work for the amateur astronomer will long be remembered, yet few who read his notes could possibly appreciate his courage. Although often in pain, he was unfailingly courteous and good humoured; he drove himself, uncomplaining, to the end. To have made his acquaintance was to admire him; to have earned his friendship is to preserve many a grateful memory.

J. G. PORTER.

HERBERT HENRY FURNER entered the Royal Observatory 1889 March 18 as a supernumerary computer; owing to ill health he resigned that position in August 1895 but rejoined in the following year. He was appointed to the permanent staff 1897 November 26 and retired on pension 1934 November 25. He was engaged on the reduction of the observations made with the Transit Circle and concerned with the formation of the various star catalogues which resulted from them. He was one of the regular observers with the Transit Circle and also with the Altazimuth ; for some time he assisted Dr Crommelin in the reduction of the observations made with the latter instrument. Keen sighted above the average, he became one of the observers of double stars with the 28-inch refractor and on the retirement of Lewis he was given charge of the instrument. An analysis of the observations of the pairs included in the programme carried out with the 28-inch equatorial over a long period of years served as the basis of a paper contributed to the *Monthly Notices* (1920 November) under the joint names of J. Jackson and H. H. Furner, " The hypothetical parallaxes of 556 visual double stars, with a determination of the velocity and direction of the Solar Motion ". In association with Sir Frank Dyson a paper " On the Earth's magnetic potential " was contributed under their joint names to the *Geophysical Supplement* (1923 May). This gave the result of a

spherical harmonic analysis based on the official Magnetic Charts for the year 1922.

Herbert Henry Furner was born 1873 September 18; he died 1952 June 26. A quick and accurate computer, of a quiet and modest disposition, he carried out to the best of his ability whatever task he undertook. He was predeceased by his wife and by their only child, a daughter, and is survived by one grandson.

He was elected a Fellow of the Society 1905 April 14.

P. J. MELOTTE.

Astronomy owes much to the keen interest of Sir RICHARD ARMAN GREGORY. The vault of heaven spreads its immensity of infinite space around the human life of this little world of men and women; astronomers, down the ages, have maintained observations and records of the universe, and have brought the reality of its beauties and the awe of its presence into the lives of their fellow creatures.

Gregory was unique in his genius for encouraging the flow of knowledge from the technician to those who, in their different circumstances of life, would further the progress of science by such forms of appreciation as was theirs—to give or to receive.

His work as Assistant Editor and Editor of *Nature* for 44 years, up to the age of 75, his connection with the British Science Guild, his Presidency of the British Association and Fellowship of the Royal Society indicate much more than technical merit, and his contribution to the literature of science is considerable. But his part in the foundation, control and establishment of the Norman Lockyer Observatory stands out as a rare achievement in his beloved Astronomy.

This enterprise, conceived by Sir Norman Lockyer as the Hill Observatory for England, at 550 feet above sea level on the high plateau of Salcombe Hill, Sidmouth, derived its funds, land and equipment from large and small donations and gifts from many friends of astronomers and their art. Its erection commenced in 1912 and its early life proceeded under the guidance of an organizing committee of well-known men of wide interests who have now passed away after doing yeoman service in the beginnings of an Observatory's life.

It was on the incorporation of the Observatory in 1916, during Sir Norman's later years, that Gregory took his real place in the picture of the Observatory and its future, although he had played a useful part in its earlier development. He became Chairman of the Council and the controlling personality, keeping together the founders and donors with their financial help and gifts of plant, equipment and land; presiding at many functions, including the unveiling by Sir Frank Dyson, then Astronomer Royal, of the marble plaque of Sir Norman by the late Sir Hamo Thornycroft, and the inauguration, by Sir Frank Dyson, of the Photographic Equatorial with its dome and annex, presented by Sir Robert Mond.

Finally, on 1948 May 1, at the Observatory, he handed over the Observatory and its control and management to the University College of the South West, Exeter; and the gift was accepted graciously by Sir William Mundy, deputy president of the College (see *Nature*, 1948 May 29). Sir Richard Gregory was elected a vice-president of the College and continued his guidance of the Observatory's destiny, until advancing years took their toll of his wonderful energies

and only the will to win remained up to his last message to the British Association in Belfast.

His wish in Heaven will be that the inspiration which during his life carried this astronomical enterprise, through 40 years of endeavour, to a University home, will keep ablaze the torch of endurance and fulfilment in the hearts of men and women of the South West of England and of astronomers and their friends, the world over.

The story of the Observatory was that of a very happy family looked after by Gregory as Chairman of Council, and by Lady Lockyer as patron hostess. The Council of the Observatory and its Research Committees included many astronomers who gave their time and knowledge willingly and effectively to its progress.

From the start, W. J. S. Lockyer was Assistant Director and then Director, until his death in 1935; and D. L. Edwards has taken his place as Director. They and their astronomical staff and attendants have maintained the Observatory and its work successfully through difficult times. In every aspect of this Observatory's life, Gregory was present with his enthusiasm and energy and appreciation of the work of those who played their part in its progress.

Sir Richard Gregory died on 1952 September 15 at the age of 88, and *Nature* of 1952 September 27 has recorded many of the ways in which he served science. This notice gives one example of special achievement in cooperation with his friends. All had to share his love of science, blended with his love of life and its actors. At Middleton-on-Sea and at social gatherings everywhere, he and his devoted wife shared enjoyment of life with others, at dinner and dance and on the playground as well as in the realm of science.

He was elected a Fellow of the Society on 1890 February 14.

W. N. McCLEAN

THEODORE MACKENZIE was born at Derby in 1876 and died in hospital at Port Elizabeth on 1952 November 17. He was brought to South Africa at the age of eleven and finished his education at the Normal College in Cape Town. On leaving school he became an assistant at the South African Public Library. He served as a volunteer during the Boer War and soon after his return to civil life gave up library work for accountancy. He became the secretary of several societies and civic organizations and was a free-lance journalist and broadcaster. The last thirty years of his life were spent at Grahamstown where he took an active part in municipal affairs.

Mr Mackenzie's chief astronomical interests were computing and the history of astronomy in South Africa. He was the first secretary of the Astronomical Society of South Africa and its President for the year 1938–39.

He was elected a Fellow of the Society on 1930 April 11 but resigned during the war years because of financial difficulties. When his financial position eased, he applied for re-admission and was re-elected on 1949 October 14.

R. H. STOY.

PROCEEDINGS OF OBSERVATORIES

Royal Greenwich Observatory

(*Director, Sir Harold Spencer Jones, F.R.S., Astronomer Royal*)

Meridian department.—The programme of observations with the Airy transit-circle has been restricted to the Sun, Moon and planets, together with stars required for the determination of the clock and azimuth errors.

During the year the following observations were obtained:—

Sun	157	Venus	54	Pallas	9
Moon	103	Other planets	77	Juno	7
Mercury	10	Ceres	5	Vesta	15
Standard stars	1931				

The new object glass for the Cooke transit-circle is now installed and is proving satisfactory in every way. Off-axis coma, which was very troublesome with the old objective, is not detectable even at the extreme limits of the field used.

The investigation into the cause of the large variations with temperature of the collimation error of this instrument is proceeding. Replacement of the object glass made necessary a redetermination of the temperature coefficients. A large reduction of these variations, which are caused apparently by a warping of the telescope tube, can be achieved by a suitable relative disposition of the component parts of the instrument. Measures in the other coordinate, affecting the zenith point, are being included in the investigation, but it seems clear in principle that errors in this direction cannot be cured by the same means at the same time. The period of waiting for the erection of the new building at the new site affords an excellent opportunity for a lengthy enquiry of this sort.

The cameras for conversion of the microscope micrometers to photographic recording were received from the makers in November, but have been returned for the correction of a number of faults.

From the observations of some temporary azimuth marks, made with one of the collimators of the Cooke instrument, on the site of the meridian group of buildings at Herstmonceux, it has been concluded that the advantage of the greater of the two available distances more than offsets the disadvantage of impaired seeing over the longer path, so that marks for both the Cooke and the Melbourne transit-circles can be sited at the maximum distance compatible with the contours of the ground and the minimum depression of the line of sight for clearance of the respective collimators.

Astrometry and astrophysics department.—The reductions in the Cape Zone $-56°$ to $-60°$ were completed in November. Position corrections depending on colour and magnitude were entered on the index cards and applied to the measured coordinates. The corrected measures have been converted to R.A. and Dec., either differentially from the residuals (where good modern places were used in computing the standard coordinates) or by conventional transformation of tangential to spherical coordinates (where only rough places were available). The cards thus contain final equatorial coordinates on the FK3 system for the 7 700

stars in the zone. A few stars in adjoining declination zones were measured on the plates and the measures have been reduced concurrently with the rest: places for these are awaited from the Cape so that the internal estimate of precision from the R.A. overlap can be confirmed.

The astrographic refractor has been used mainly for photographing the four brightest minor planets. During the year the following numbers of plates were secured: on Ceres 13, on Pallas 24, on Juno 30, on Vesta 34; on other minor planets 19; and on various comets 27. Amongst 15 miscellaneous plates taken are some on Jupiter's Galilean satellites, and on star fields around the artificially occulted Moon. Measurement of all plates is well up to date.

In connection with the minor planet programme a series of 45 plates exposed on a suitable star field over a wide range of azimuth has been obtained for investigating the accidental and systematic errors affecting photographs taken at large hour-angles.

Tests of the $5\frac{1}{2}$-inch $f/5$ Ross aircraft reconnaissance lens mounted on the astrographic equatorial show that the existence of appreciable coma will make positional work with the lens inadvisable beyond 3° from the axis. For search purposes, however, the full 10° field will be useful in comet and minor planet work, when ephemerides are lacking or are of low precision.

On the 36-inch Yapp reflector the programme of examining Ko sub-giants for luminosity effects correlated with anomalous trigonometric parallaxes is now directed towards fainter stars. On poor nights or at R.A.s where no programme stars are scheduled the telescope is being used to accumulate a collection of low-dispersion spectrograms of standard stars in the Morgan, Keenan and Kellman *Atlas*. A total of 178 exposures on 93 stars was secured during the year.

Eclipse of 1948 *November* 1.—Traces of the Moon's limb, with the baseline revised to take account of systematic terms obtained by comparing different librations, have recently been received from Washington, and the final reduction is now in hand; the changes which have been made will be reflected in altered corrections to the Moon's place, and to some extent also in the computed probable errors.

Eclipse of 1952 *February* 25.—Some experiments have been made to see whether the quality of the photoheliograph films, which were rather over-exposed at both stations, can be improved by reducing them. It seems clear, however, that the bad seeing on previous days had made the determination of the best focus very difficult; there is evidence from the En Nahud station that during the eclipse the seeing improved near mid-eclipse (and that the focus must have been nearly correct), but even at mid-eclipse most of the images are poor. Reduction of the cine records will probably have to depend on limb data from other sources.

Photoheliograph and spectrohelioscopes.—The Sun was photographed at Herstmonceux on 311 days, thus exceeding by 12 days the previous record at Greenwich in 1938. Up to December 8 only one day, September 9, is unrepresented in the combined Greenwich–Cape series. Cape negatives in duplicate have been received up to 1952 June 30.

The measurement of the combined series of photographs has been made from 1950 January 7 to 1952 February 29. Tables of the mean daily areas and mean latitudes of sunspots for each solar synodic rotation for 1947 have been published in *Monthly Notices* 1952. The *Greenwich Photoheliographic Results* for 1939

have been published. The reproduction of the volumes for 1940 and 1945 has been made, but copies for distribution have yet to be bound.

The Sun's disk was observed in Hα on 168 days. On 53 days observations were possible for not more than 15 minutes. As in previous years, observations were directed to (1) the occurrence of flares, (2) photometer measures of normal bright flocculi and of flares, and (3) the location and measurement of line-of-sight motions shown by disk markings and limb prominences.

Eight flares were observed during the year. This number represents one flare per 8½ hours of observation, and clearly indicates the present low level of chromospheric activity. These flares were all below importance 3.

The S.E.A. (sudden enhancement of atmospherics) recorder was operating throughout the year. The traces indicate the occurrence of 16 solar flares in Greenwich daylight hours, but probably none of these flares rose to importance 3 on the international scale. A few additional minor flares may also be indicated, but there is uncertainty because of the smallness of the trace impulses in question.

44 sets of photometric measures were made under the above heading (2), and 253 measures under heading (3). A velocity of 210 km/s outwards from the Sun was measured on June 23 for a dark filament of surge type associated with a flare of importance 2.

A few spectra of the Hα region were obtained with the grating of the Newbegin spectrohelioscope. These spectrograms have been passed through the microphotometer at Greenwich and instrumental corrections were obtained.

The design of several new instruments to be installed in the Solar Building is under consideration. The air-conditioned spectrograph cellar will contain a high-dispersion liquid-prism spectrograph and a large spectroheliograph using three solid glass prisms. The theoretical maximum resolving power of the latter system will be approximately 56 000 at Hα and 264 000 at the *K* line. Both instruments will be fed by means of a 10½-inch objective at ground level, eight feet above the optical level of the spectrographs. One of several possible means of scanning the Sun's image, using a fixed spectrograph and avoiding all vignetting, will be adopted in the spectroheliograph. For obtaining daily photographs in monochromatic light a birefringent polarizing filter of the Lyot type, with a line-width of 0·65 A, is on order and will be mounted on the 6-inch Newbegin equatorial telescope in the Solar Dome.

Time department.—Astronomical observations for time determination have been made throughout the year at Abinger with a Bamberg broken transit instrument and at Greenwich with a small reversible transit. At Abinger 246 observations were obtained on 146 nights and at Greenwich 201 observations on 135 nights.

Several analyses of the time observations have been carried out, including an experimental investigation making use of punched-card equipment. In the light of the results obtained, some modifications were introduced into the methods of making and reducing observations. Further studies are in progress.

The accuracy of the transmitted time signals showed a significant improvement following a change in policy in the early part of the year. The signals are now kept as closely as possible in agreement with the currently observed astronomical time, while the provisional uniform time system required for accurate frequency standardization is established on the basis of the most recent determinations of the apparent annual fluctuation in the length of the day. This procedure minimizes

the risk of disturbance to the time service caused by unpredictable changes in the annual fluctuation.

Minor modifications were carried out on two of the Observatory's ring-crystal oscillators, resulting in a marked improvement in short-term stability. Regenerative frequency dividers of a new design have been installed, and for applications calling for accurate seconds signals, phonic motors have been replaced by electronic pulse dividers providing output pulses with a scatter of about one microsecond. Two experimental quartz-crystal oscillators have been installed, and a third is approaching completion. The short-term performance is significantly improved, particularly in one case where the crystal, when mounted in a conventional circuit, was regarded as sub-standard. The high stability now achieved has made it necessary to design new equipment for frequency measurement, and this is under construction.

Optics laboratory.—The final stage in the construction of the Photographic Zenith Tube has now been reached. The auxiliary system which comprises the mounting and adjustment of the mercury horizon is essentially self-contained and without influence on the design of the rest of the instrument; its detailed treatment has consequently been deferred and has been the main outstanding feature of the instrument to be dealt with. In the course of the last year the design and construction have been completed. As has been indicated previously, the basin containing the mercury reflector is floated in mercury. Its height is controlled by plungers which can be manually operated from outside the instrument. The original system of control proved unsatisfactory but, as a result of further experiment, has now been replaced by a system which functions adequately. In addition to the optical criterion of height, the micrometer system with which the lower end of the distance rod (used for setting the objective to the correct height) makes contact may be used as an alternative and mechanical criterion.

Considerable progress has been made in the design of a machine for measuring the stellar plates of the P.Z.T., and a full-scale model of the suggested arrangement has been constructed. The design is such that only a slight readjustment is required to change over from a visual to a microphotometric criterion of setting. The latter has several features of merit in its favour and has been the subject of independent investigation. The requisite auxiliary electronic equipment has been constructed, and it is hoped to resume further experimental work when suitable photocells have been acquired.

In connection with the International Longitude Programme for the International Geophysical Year 1957–58, an investigation of photoelectric recording of the times of stellar transits has been commenced. It was considered that, at any rate in the initial stages, the optical system of the Horizontal Transit Instrument was appropriate; to some extent, therefore, the two lines of development have been merged. With an artificial star as source, the magnitude of which can be varied by optical wedges, occultations of the image by straight edge, wire and graticule, at slow motion, i.e. statically, have recently been measured using the spot on a C.R.O. screen as indicator. Further work is in progress.

Nautical Almanac Office.—The 1953 editions of the annual publications of the Office and the four-monthly parts of the *Air Almanac* for 1952 September to 1953 August have been published during the year. The two parts of the *Air Almanac* for 1953 were the first issues of the single publication produced jointly by the Nautical Almanac Offices of the Royal Greenwich Observatory and the U.S. Naval

Observatory as described in last year's report. No other changes have been made in these publications. The editions for 1954 are at various stages of publication. One volume of A.P. 3270 "Sight Reduction Tables for Air Navigation" has been published and two volumes of H.D. 486 "Tables of Computed Altitude and Azimuth" have been issued during the year.

The annual discussion of observed occultations for 1948 has been published in the *Astronomical Journal* and those for 1949 and 1950 will be published together. The combined list of all observations for the years 1943 to 1947, which will form an Appendix to *Greenwich Observations* 1939, has been published and distributed to observers. During the year 23 occultations were observed at Herstmonceux by the staff of the Office.

At the Rome meeting of the International Astronomical Union agreement was reached on a number of resolutions, concerning the fundamental ephemerides of the Sun, Moon and planets, proposed jointly by the U.S. and H.M. Nautical Almanac Offices. The sense of these resolutions is generally to increase the theoretical and numerical precision of the ephemerides; as a consequence, most of the work of the Office will have to be revised. Some of the work would hardly be possible without the help of modern computing equipment.

These changes are not to be introduced into the *Nautical Almanac* until the edition for 1960, but work is already in progress for the years from 1960 onwards. The revised values of the nutation and aberration are, however, to be introduced into the apparent places of stars observed with Photographic Zenith Tubes from 1954; the nutation has been evaluated from the new series of 69 terms on the punched-card machines, and day numbers for use with P.Z.T. stars have been prepared for 1954.

In connection with these revisions a detailed investigation has been made into the higher-order terms in the reduction of star positions from mean to apparent place.

Royal Observatory, Edinburgh

(*Director, Professor W. M. H. Greaves, F.R.S., Astronomer Royal for Scotland*)

Stellar spectrophotometry.—The spectrophotometric investigations of early-type stars (mostly brighter than fifth magnitude) have been continued. The scheduled observing programme, which is considerably ahead of the measurements and reductions, is nearing a state of completion and it is hoped to carry out the remaining observations during 1953. Forty-nine spectra were obtained on twenty-eight nights during 1952.

The temperature control of the Hilger spectrograph attached to the 36-inch reflector and the heating elements within the spectrograph have both been replaced. The original temperature control, which used a Wheatstone bridge and a mechanical relay system, broke down in 1951 March, and the control has since been carried out by hand during exposures at the telescope. At the time of writing this report an electronic control unit, designed and constructed by Mr H. Seddon, is being installed. This unit controls the temperature by a continuous variation in the heating current and should, therefore, maintain a more constant temperature than the previous system which employed an intermittent heating current.

The original heating elements of the spectrograph, which have been giving some trouble in recent years, were replaced during the summer by new ones.

Thirty-three asbestos woven nets forming three circuits are employed as previously, but the leads of each net are now brought to terminals on the outside of the spectrograph case, an arrangement which facilitates the quick detection and repair of faults.

The spectra of stars of type B1 have been measured and reduced and the copy for press of an Observatory Publication giving the results is being prepared. The star β Cephei has been found to show a long-period variation in the intensity of its Hα line and there is some evidence of (smaller) corresponding variations in the intensities of Hβ and Hγ.

Dr R. Wilson has completed his investigation of the series $5\ ^2G - n\ ^2H^o$ of ionized helium which he has found to be present in stars of type O. This investigation has been incorporated in a thesis for which the Ph.D. degree has been awarded by the University of Edinburgh. Dr Wilson's spectrophotometric work on the Blue Sun of 1950 September was also incorporated in this thesis.

Solar work.—The first six months of the year were occupied with re-erecting the combined spectrohelioscope and spectrograph on a new and better site in the Transit House. The opportunity was seized of incorporating a number of improvements which had been outstanding. These included: (1) a new collimating lens, of 6 in. aperture and 18 ft. 3 in. focal length, constructed by Messrs Cox, Hargreaves and Thomson, Ltd. to illuminate the full aperture of the 5½-inch plane grating; (2) a double slit of special construction at the primary focus; and (3) a line-shifter of larger aperture for the spectrohelioscope. The primary image is now formed by light from the Cormack coelostat equipment, which, as described in the last report, is on loan to us from the Royal Society of Edinburgh. The fused quartz mirrors of this instrument, of 10 inches and 8 inches aperture respectively, provide a welcome assurance against appreciable changes of focal length under the action of solar heating. Adjustments and tests of performance were carried out throughout the remainder of the year.

Daily disk drawings in white light and observations in Hα light with the spectrohelioscope were resumed in August. Two flares, of Classes 1 and 2 respectively, were observed during the last quarter of the year.

The photometric reduction of 400 plates of chromospheric and prominence phenomena, taken during the years 1948–51, was completed by Dr Ellison early in the year. The results of this work have been published, under the title "A Photometric Survey of Solar Flares, Plages and Prominences in Hα Light", in *Publications of the Royal Observatory, Edinburgh*, Vol. **1**, No. 5, 1952.

Dr Mary Conway's investigation of Hα Line Profiles in Prominences has been published (*M.N.*, **112**, 55; *Edinburgh Communication*, No. 3).

At the beginning of the year the photoelectric spectrophotometer designed and used by Dr M. J. Smyth was transferred to the Optical Room, where it is fed by the 16-inch siderostat. Two selected 931–A photomultipliers are used to measure intensities in different regions of the solar spectrum, and experiments with various methods of compensation for "seeing" have been carried out.

Reduction of the previous year's photoelectric measurements of the wings of the solar *K*-line, made to investigate possible asymmetries due to corpuscles emitted from flares or M-regions, is now complete. Absorption immediately following two central flares of Class 2 which were observed did not exceed 0·8 per cent; and no absorption of as much as 0·3 per cent was observed twenty-one hours after a flare of Class 3, which was followed by geomagnetic disturbance.

There was, however, some evidence for absorption of the order of 0·5 per cent during the magnetically disturbed month of September, although the effect did not correlate with any specific magnetic disturbance. These results have been included in a thesis by Dr M. J. Smyth, "A Spectrophotometric Investigation of Solar Corpuscular Radiation", for which the Ph.D. degree has been awarded by the University of Cambridge.

An investigation of published coronal data for 1950 has revealed a relationship with recurrent geomagnetic storms which differs from that found by some workers during the previous sunspot minimum. A note by Dr Smyth on "The Corona and Geomagnetism" has been published (*The Observatory*, **72**, 236, 1952).

Astrographic Catalogue.—The Perth Section, Declination $-38°$ (Volume III of the measures made at Edinburgh of plates taken at Perth, Western Australia), published under the auspices of the International Astronomical Union, was distributed during 1952 March from this Observatory. This issue concludes the publication of those zones ($-38°$, $-39°$ and $-40°$) for which the plates were measured at Edinburgh.

Schmidt telescope.—The corrector plate of the 24/16-inch Schmidt telescope, which had been returned in 1951 to the makers (Messrs Cox, Hargreaves and Thomson, Ltd.) for the application of anti-reflecting coatings of magnesium fluoride, was replaced in the telescope and tested. The haloes round the images of bright stars, caused by a single internal reflection at each surface of the corrector plate, were found to be much reduced in intensity (see *The Observatory*, **72**, 60, 1952).

The ghost images of bright stars have since been investigated. These are formed by light which is scattered from the emulsion, received by the spherical mirror, and thrown back, as a parallel beam, to the corrector plate. Each surface of the corrector plate returns about one per cent of this beam to the mirror. It is then re-focused on the film at a point on the opposite side of the axis symmetrically placed with respect to the primary image. The ghost image is a complex pattern 4′ in diameter, whose structure is determined by the aberrations introduced at the corrector plate reflections. The precise position of the ghost, relative to the primary image, provides a sensitive means of squaring on the corrector plate. There is some point in doing this: for, although the perfection of the primary images is unaffected by squaring on, in stellar photometry it is desirable to know the position in the field of possible ghosts of low intensity.

Further tests and adjustments to the instrument occupied the greater part of the year: progress was greatly hampered by persistently cloudy weather, especially in the autumn months. Several series of exposures were completed for squaring on the film holder, for investigating the depth of focus and the quality of the in-focus and out-of-focus images. The images appear to be of extremely high quality over the whole field of 4° diameter. The focus is so highly critical that a movement of the film along the optical axis of amount 0·002 in. produces a perceptible enlargement of the in-focus image. The film holder has been squared on to the same order of accuracy.

Temperature changes, having a range of 20 deg. F between different observing nights, have produced no perceptible departure from critical focus, indicating that expansion errors are less than the depth of the focal surface, about 0·002 in. It is therefore clear that the invar rod suspension system, which was designed to maintain the film holder at a fixed distance from the mirror surface, has proved

adequate for this purpose. Without such temperature compensation the expected range of movement for this change of temperature would be about 0·03 in., which could not be tolerated in an instrument designed for stellar photometry.

Some exposures have been made upon the North Polar Sequence and these will be measured on the Kipp and Zonen actinometer for the determination of the off-axis corrections.

Stellar scintillation.—Recordings made with the photoelectric scintillometer have been continued during the year. The object has been to investigate some problems raised by the earlier work, an account of which has now been published by the Society ("Some Experiments on the Scintillation of Stars and Planets" by M. A. Ellison and H. Seddon, *M.N.*, **112,** 73; *Edinburgh Communication*, No. 4).

Tests on 931-A photomultiplier tubes.—Some tests have been described in a paper by Dr M. J. Smyth (*M.N.*, **112,** 88; *Edinburgh Communication*, No. 5). This paper describes *inter alia* a convenient method of examining local cathode sensitivity. It was found that some tubes have markedly uneven sensitivity over the cathode surface whereas others are very satisfactory in this respect. The tubes tested included that used in the investigation of scintillation.

Blue Sun.—The results of Dr R. Wilson's spectrophotometric investigation of the Blue Sun of 1950 September have been published (*M.N.*, **111,** 478; *Edinburgh Communication*, No. 2).

Radio equipment.—Recordings of sudden ionospheric disturbances associated with solar flares have been continued on a frequency of 27 kc/s. A list of such occurrences during 1952 has been distributed as previously to institutions and persons requesting them.

Facilities have been given to Mr J. A. Ratcliffe, of the Cavendish Laboratory, to instal in the Bamberg Hut a long-wave receiver for ionospheric investigations.

Seismology.—Our thanks are due to Mr H. Tillotson for continuing to undertake the reading of the Milne–Shaw seismograph records and for answering correspondence arising from them.

Visitors.—Visiting scientists during 1952 included Mr M. K. Das Gupta, Miss Margaret Harwood, Professor F. Larink, Miss Barbara Middlehurst and Mr A. M. Newbegin. We were pleased to welcome a party from the British Astronomical Association (Scottish Branch).

Royal Observatory, Cape of Good Hope

(*Director, Dr R. H. Stoy, H.M. Astronomer*)

Reversible Transit Circle.—The observations for the new catalogue begun in 1951 were continued. The stars south of $-80°$ have received preferential treatment in the hope that this part of the catalogue may be completed in 1954. In all, 8 266 transits were observed during 1952, including the following observations of bodies in the solar system:—

Sun	131	Jupiter	22	Vesta	39
Moon	34	Saturn	31	Juno	18
Mercury	48	Uranus	30	Pallas	24
Venus	102	Neptune	21	Ceres	14
Mars	29				

Photographic Zone observations.—Work on this programme has proceeded steadily. The typescript for the catalogue for the zone $-52°$ to $-56°$ (9215 stars) was prepared for direct photolithographical reproduction and that for the $-60°$ to $-64°$ zone (7053 stars) started. The measurement of the $-64°$ to $-68°$ zone (5000 stars) was completed. The computation of the standard coordinates for the $-68°$ to $-72°$ zone (4400 stars) was also completed and this zone is now ready for measurement.

Parallax programme.—The observations for the main part of this programme were completed in 1951, but 91 plates intended for the determination of proper motion were obtained in 1952 January before the Victoria Telescope was dismounted to have roller bearings fitted to its declination axis. 1836 plates were measured for parallax and 121 were rejected, leaving 4575 still to be measured. Parallaxes were derived for 48 stars, none of which had a parallax previously determined at the Cape.

Radcliffe section.—Of the 121 nights assigned for the use of the Cape during 1952, 37 were completely clear, 39 more than half clear, 24 less than half clear and 21 completely cloudy. $68\frac{1}{2}$ nights were used for spectroscopic observations, $18\frac{1}{2}$ nights for direct photography, 11 nights for photoelectric photometry and 2 nights for work in connection with the photoelectric observation of an occultation of Antares.

The working list for the radial velocity programme was slightly extended during 1952 to include a few miscellaneous stars of special interest and a number of extra standards recommended by Commission 30 of the International Astronomical Union. The total number of stars included in the present programme is 450, of which 24 are standard stars. The majority of the stars on the programme have been selected on account of large parallax or because they are within the area of $6° \times 6°$ surrounding one of the Kapteyn Selected Areas Nos. 140–206 and their annual proper motion as given in the *G.C.* exceeds $0''{\cdot}1$.

793 spectra were obtained for this programme during 1952. 700 spectra were measured and reduced, some of them in duplicate. About 50 spectra, mostly taken at the beginning of the programme before the observers and measurers were sufficiently experienced, have been rejected. Of the stars now on the working list, all but 11 have been observed at least once, 205 have been observed twice, 123 three times, 24 four times and 15 five or more times. It is intended that each star should be observed at least four times. The general interagreement between the results so far obtained indicates that this number will be perfectly adequate for all ordinary stars.

131 direct photographs were taken at the Newtonian focus. Of these, 73 were for the programme which aims to provide a photometric durchmusterung for the central portions of the E regions and the Kapteyn Selected Areas Nos. 140–206. The other 58 were long-exposure photographs of extragalactic nebulae and clusters and form the beginning of what is hoped will be a systematic survey in several colours of various southern objects which promise interesting fields of study. The ten largest extragalactic nebulae are receiving special attention.

Dr Evans has completed a study of the surface photometry in blue light of the southern elliptical nebulae with integrated magnitudes brighter than $11^{m}{\cdot}0$, and has also investigated the nucleus of the spiral nebula NGC 6744 which appears to follow a similar brightness law.

The photoelectric photometer designed and built at the Leiden Observatory for use at the Cassegrain focus of the Radcliffe Reflector was delivered in 1952.

During the months of June, July and August, the Cape observers made a serious attempt to use this photometer. Though its initial behaviour was very disappointing, there is every indication that it will become a very convenient and useful instrument as soon as the various teething troubles have been overcome and a more sensitive multiplier cell has been fitted.

Stellar photometry.—The principal photometric programme carried out during 1952 was intended to determine the relative zero points of the various E region sequences and to connect them to the sequences of photoelectric magnitudes that have recently been established in the northern hemisphere for the Pleiades, Hyades, Praesepe and IC 4665.

Four stars were chosen in each region and the photoelectric photometer attached to the Astrographic Refractor was used for comparing these stars together in two colours. The observations to compare four stars in Region A with four stars in Region B were made in the following order: A1, B1, A2, B2, ... B4, A1, B1, A2, ... with the appropriate observations of the sky background between every other star. The observations were begun about forty minutes before the two regions were at equal zenith distance and continued to about forty minutes afterwards. Each such E, E region comparison was made on at least six nights and each E region was compared with the four adjacent regions. A subsidiary programme with the same instrument compared the zero-point stars in each region with a wide selection of other stars in that region to ensure that the zero point defined by the four stars was essentially that of the region as a whole.

It is believed that in this manner the relative zero points of the various E region sequences have been established with a standard error of about $\pm 0^{m}\cdot 003$, while the zero point of the E regions as a whole has been transferred to Pleiades, Hyades and Praesepe with a standard error of about $\pm 0^{m}\cdot 005$.

Observations for this programme were made on 154 nights and 5 405 two-colour observations were obtained. Other photoelectric observations that were made in 1952 include 728 observations of stars in the E regions made with the new photometer attached to the Victoria Telescope, 563 observations of fainter stars in the E regions made with the Cassegrain photometer of the Radcliffe Reflector and 1 156 observations made for the "Bright Star Programme" with the photometer attached to the Astrographic Refractor.

The work on the magnitudes for this "Bright Star Programme" of the 850 stars brighter than the fifth visual magnitude south of $+6°$ declination was completed in 1951. During 1952 an attempt was made to finish the complementary work on the photoelectric colours. The 9 800 observations made in the years 1949–1952 were re-examined, reduced as far as possible to a standard system and ledgered. A list of definitive magnitudes and colours for these 850 stars was compiled. About 25 of the stars are included in the three-colour photometry recently developed at the Yerkes and McDonald Observatories. Through the kindness of Dr H. L. Johnson magnitudes and colours for these stars were communicated before their publication. The agreement between the two sets of observations seems to be extraordinarily good. (Average accidental difference for magnitudes $0^{m}\cdot 013$ and for colours $0^{m}\cdot 010$.)

If BF denotes the blue Fabry magnitude as measured at the Cape and CP the Cape observed photoelectric colour,

$$\mathrm{BF} = B + 0\cdot 205(B-V) + 0\cdot 05(U-B) - 0\cdot 19$$

and

$$\mathrm{CP} = 0\cdot 964(B-V) - 0\cdot 188,$$

where *U*, *B* and *V* denote the ultra-violet, blue and visual magnitudes of the three-colour photometry. The most interesting thing about these comparisons is the way in which BF depends on *U*, while CP does not.

Photoheliograph.—The Sun was photographed on 344 days, two photographs being taken each day. Visual observations to determine the orientation were made weekly and photographic observations for the same purpose every two weeks. The plates have been forwarded to Herstmonceux for measurement at the Royal Greenwich Observatory where similar plates are taken.

Occultations.—60 observations of 39 phenomena were made with various telescopes at the Observatory. The reappearance of Antares at the dark limb on April 13 was observed photoelectrically both at Pretoria and at the Cape. The observation at Pretoria, which was made possible through the kind cooperation of the Electronics Sub-Division of the National Physical Laboratory of the C.S.I.R., was extremely successful. The trace secured recorded both the reappearance of Antares itself and also that of the companion. A discussion by Dr Evans of these observations has been submitted to the Society.

Variable stars.—During 1952 Mr R. P. de Kock made 6961 observations of 175 long-period variable stars using the Six-inch Telescope. He has also kept a watch on two "flare" stars 013418 UV Ceti and 203501 AE Aquarii. Shorter series of observations were made by Mr A. Morrisby with the Seven-inch Telescope and by Mr S. Archer with the Five-inch.

Double stars.—160 measures of double stars were made with the Seven-inch Telescope by Mr W. P. Hirst, one of the local amateur astronomers.

Publication of observations.—The *Third Cape Catalogue for 1925·0* and *Cape Annals*, Volume XVI (Details of parallax determinations) were distributed during 1952. It is understood from the printers that the *First Cape Catalogue for 1950·0* and *Cape Annals*, Volume XV (Details of parallax determinations) are at the binders and should shortly be ready for distribution.

Armagh Observatory

(*Director, Dr E. M. Lindsay*)

Equipment.—A new steel declination axis for the 12/18-inch Schmidt made by a local firm results in a perfectly smooth slow-motion movement in declination. Test photographs show that the camera is now ready for use. The design of an airglow spectrograph was completed by Dr Armstrong and the optics are under construction by Messrs Cox, Hargreaves and Thomson. The spectrograph is made possible by a grant of £800 from the Gassiot Committee.

Observations.—Over 100 plates have been taken with the meteor cameras by Dr Öpik at Armagh and Captain Wright at a site 20 miles from the Observatory. Dr Armstrong continued his experiments on night-sky radiation and carried out laboratory experiments on the effect of background light on Fabry–Perot interferometer fringes. Using the 60-inch Rockefeller reflector at the Boyden Station of the Harvard Observatory and attached photoelectric photometer, the Director obtained observations on colours of faint Cepheids and on eclipsing variables. With the ADH, data for colours, magnitudes and spectra were obtained for the Coal Sack and nearby comparison regions, and for emission objects in the Magellanic Clouds. With the same instrument long-exposure photographs were taken of selected regions in the Southern Milky Way. Meteorological observations and reductions were continued by Miss Sheelagh Grew.

Dr Öpik has worked on the theory of meteor phenomena, in particular of meteor radiation and ionization.

Publications.—Contributions Nos. 7 and 8 and *Leaflets* Nos. 10–14 were distributed. *Leaflets* 11–15 have been published. *Contribution* No. 9 on "A Climatological and Astronomical Interpretation of the Ice Ages and of Past Variations of Terrestrial Climate" by E. J. Öpik will shortly appear as a monograph. *Contribution* No. 10 on "A Note on the Use of the Fabry–Perot Etalon for Upper Atmosphere Temperature Measurement" by E. B. Armstrong is in the press. Two papers, "Meteorology at the Boyden Station of the Harvard Observatory" by E. M. Lindsay and "The Photoelectric Light Curve of V525 Sagittarii" by G. G. Cillié and E. M. Lindsay will be distributed as Harvard Reprints. Dr Öpik has continued to edit *The Irish Astronomical Journal* published by the Irish Astronomical Society.

Visitors numbered 2085, a slight increase over last year. They included the Astronomer Royal, Dr Martin Davidson and over fifty members of the British Association.

Lectures in the Department of Astronomy, Queen's University, Belfast, were given twice a week by Dr Armstrong.

The Director was absent for most of the year as Acting-Superintendent of the Boyden Station, returning in December.

The Observatories, Cambridge University
(*Director, Professor R. O. Redman, F.R.S.*)

Reconstruction and re-equipment.—The new solar research tunnel has been completed and the McClean coelostat and telescope, after a mechanical overhaul, have been installed in their new positions there. The original glass mirrors have been replaced by 16-inch fused silica mirrors by Messrs Cox, Hargreaves and Thomson, with a gratifying improvement of optical performance. The mechanical parts for the new solar spectrograph are approaching completion in the Observatories' workshop. A temporary mounting is in use for testing purposes.

The 16/24-inch Schmidt telescope is being assembled at Messrs Grubb Parsons' works; 1953 June is the present estimate of delivery date. The 36-inch reflector should follow about a year later.

Solar research.—Three members of the staff (Professor Redman, Dr Blackwell, Dr von Klüber) spent about seven weeks at Khartoum for the total solar eclipse of 1952 February 25. They were accompanied by Mrs von Klüber and were joined there by Professor H. Zanstra (Amsterdam). The eclipse took place in good weather and nearly the whole programme of observations was completed successfully.

To measure the distribution and polarization of light in the corona, six photographs, each with four simultaneous exposures of the corona, were obtained with a quadruple coronagraph of aperture 3 in., focal length 80 in. Three images were obtained through polaroid, with planes of polarization separated by 60°, and the fourth in unpolarized light. No other filter was used. The plates were all standardized for photometry and some preliminary work has been done towards the lengthy measurements which will now be required. The photographs have also been compared with observations of the green coronal line, made at various stations at the time of the eclipse with Lyot coronagraphs.

Measures of the surface brightness of the corona out to a radius $2{\cdot}5\,R_\odot$ were made with a lead sulphide cell, working at an effective wave-length about $2{\cdot}0\,\mu$, and a photomultiplier working at about $0{\cdot}43\,\mu$, using a 20-inch $f/2{\cdot}25$ reflector. Discussion of the results, which support the current theory of a dust corona, has been completed and a paper communicated to the Society.

The ultra-violet spectrum of a prominence was photographed with the Hills quartz spectrograph. Photometry of the hydrogen Balmer continuum has permitted calculation of the electron density, assuming the temperature, and also an estimate of the thickness of the prominence structure. The work has been completed and is in course of publication.

To measure the line widths and hence the kinetic temperature, photographs of the chromospheric spectrum were taken with a large slit spectrograph, using the second order of a 6-inch Rowland concave grating in a Wadsworth mounting. Wave-lengths 5550–6040 A were covered at second contact, and 3430–4110 A at third contact, the dispersion being about $2\frac{1}{4}$ A/mm. The plates were standardized for photometry and contain a large quantity of good material. Only preliminary measurements have so far been carried out.

The expenses of the expedition were covered by a grant from the Joint Permanent Eclipse Committee, whose Secretary, Professor F. J. M. Stratton, was particularly helpful. The assistance of a number of organizations and individuals at Khartoum must also be gratefully acknowledged: the Civil Secretary's Office (Mr H. Colville-Stewart), the R.E.M.E. unit at Fort Stanley (Major G. C. Malloy), the Survey Department (Messrs R. C. Wakefield and D. F. Munsey), University College (Professor N. F. Astbury), Mr R. Dickinson and Mrs A. Colville-Stewart.

The microphotometer has been reconstructed, chiefly with measurement of eclipse photographs in mind. It now provides magnifications from 5 : 1 to 100 : 1 between plate and record, and also uses a pen recorder. Although it has already been much used in its new form, some minor faults have still to be rectified.

A value of 6 400 deg. K has been deduced for the temperature of the solar chromosphere, from intensity measurements on rotational fine structure of CH bands in spectrograms obtained at the 1940 eclipse. The work is being continued, using the spectra of other molecules also, on both 1940 and 1952 photographs.

The infra-red spectrometer has been improved during the year and now gives a resolution equal to that shown in the McMath Hulbert Observatory's *Photometric Atlas*. It has been used to measure centre-to-limb variations of the equivalent widths of Fraunhofer lines. The possibility of using an interferometer with this spectrometer has been explored, and a preliminary model constructed.

Hale's measurement of the general magnetic field of the Sun has been rediscussed in a paper communicated to the Society, using modern data regarding the Zeeman effect. His results remain essentially unaltered.

Stellar photometry.—Some improvements have been made to the pulse-counting photometer, chiefly to combat the effects of very large voltage changes which are still liable to occur in the mains supply. Although the summer season was good for solar work, it was poor for stellar photometry. The programme of measurement of magnitudes and colours of dwarf stars ($\pi > 0''{\cdot}05$) has been continued; 62 stars are finished, 55 have been observed incompletely.

The preparation for publication of the $+15°$ Selected Areas programme is now almost completed. Photoelectric accidental errors are considerably higher than at first hoped for, the standard error being $0^{m}\cdot06$ for one measure in the blue and $0^{m}\cdot045$ in the yellow. The chief source of trouble is irregular sky transparency. On the other hand, the systematic agreement between photoelectric and photographic measures is quite satisfactory.

A photometric orbit has been computed for GO Cyg, from photoelectric observations in two colours. Similar work for TX Cas is in progress.

In view of a reported variation in the magnitude of Neptune during 1950, with a period agreeing with that of the spectroscopically measured axial rotation, 62 photoelectric measures, each in two colours, were made on ten nights between February 20 and April 26. After allowing for changing distance from the Earth, no evidence for any variation of light greater than about $0^{m}\cdot04$ could be found, and no sign of periodic variation.

Optics.—A theory of error balancing in Schmidt spectrograph cameras has been worked out, including the arrangement now used at Mount Palomar, where in the coudé spectrograph the corrector plate is placed almost in contact with the grating and is traversed twice by the light.

The effect of central obstruction on the three-dimensional diffraction images formed by an aberration-free monochromat has been calculated for an obstruction ratio 0·71.

Mechanical improvements on the 8-inch two-plate Schmidt–Cassegrain camera have been completed. Work on the 12/15-inch system has been continued. Experiments have been made on the technique of polishing stainless steel mirrors.

Some of this optical work has been supported during the past three years by a grant from the D.S.I.R., whose assistance is gratefully acknowledged.

Other investigations.—Good progress has been made with the measurement of infra-red properties of thin metallic films, using the apparatus mentioned in last year's report.

Spectrophotometric measures of W Ser, from spectrograms obtained at the St. Michel Observatory, Haute Provence, have been completed. During the summer Dr Beer obtained infra-red spectrograms of the eclipsing variables β Per and RZ Cas at St. Michel, by courtesy of the Directors, and the measurement of these is now proceeding.

Library.—The thanks of the Observatories are due to Professor F. J. M. Stratton for the gift of a large number of publications and reprints.

Personal.—Mr J. A. Torrance, research assistant to Dr Linfoot, resigned in February and Mr M. W. Ovenden, Junior Observer, at the end of the year.

The Observatory Club held fourteen colloquia during the year. The speakers included Dr D. Barbier, Dr H. Elliot, Professor W. H. McCrea, Dr P. Wellmann, and Professor H. Zanstra.

Cavendish Laboratory

(*Director, Sir Lawrence Bragg*)

1. *Solar*

1 (*a*) *Routine observations.*—Regular observations have been maintained of the intensity and polarization of the radio emission from the Sun on wave-lengths of 1·7 m and 3·7 m.

1 (*b*) *The distribution of "brightness" across the solar disk.*—Further observations have been made with interferometers of variable aperture to determine

the distribution of radio "brightness" across the solar disk at wave-lengths of 1·4 m, 3·7 m and 7·9 m (**1**). At 1·4 m and in some of the observations at 3·7 m a new method has been used which avoids the necessity for assuming that the Sun has spherical symmetry. In this method the axis of the interferometer is altered so that its projection on the solar disk makes a number of different angles with the solar rotation axis; by determining the variation of the "visibility" of the fringes with aperture for each of a number of axes which cover a range of 180° on the solar disk, it would be possible to determine unambiguously any distribution across the Sun. Unfortunately, at the latitude of Cambridge, it is not practicable to cover the full range of angles with aerials which can only be moved in a horizontal plane, but observations covering a range of 90° have been made, and these make it possible to determine a mean distribution on the assumption of rotational symmetry.

The contours of "brightness temperature" derived in this way at a wave-length of 1·4 m show that the corona extends further (by about 20 per cent) in the equatorial plane than towards the poles. Similar results have been obtained at a wave length of 3·7 m.

Even in the absence of appreciable sunspot activity a considerable variation in the shape of the corona has been observed from day to day at 1·4 m. There is some evidence to show that regions of increased brightness are associated with regions where the intensity of the coronal green line (as determined at the limb a few days before and after the radio observations) is enhanced.

A detailed analysis has been made in an attempt to account for the observed average distribution of radio "brightness" at wave-lengths of 60 cm, 1·4 m, 3·7 m and 7·9 m in terms of emission by free-free transitions in the corona (**2**). It has been found impossible to account for the observations in terms of an isothermal corona; the radio observations suggest that the electron temperature decreases rapidly with increasing radius (from a value of 10^6 deg. K at 1·2 $R_\odot$ to a value of 10^5 deg. K at about 3 $R_\odot$, and that the electron density at radii greater than 2 $R_\odot$ decreases more slowly than the conventional model (**3**).

1 (*c*) *The structure of the outer corona.*—It was shown previously that observations of the occultation of a radio star by the solar corona might provide important information on the electron density in the outermost layers of the corona (**4**); observations were made in 1950 and 1951 June when the intense radio star in Taurus passed within about 4·6 $R_\odot$ of the Sun, but on both occasions intense sunspot activity prevented any useful observations. In 1952 June successful observations were made at wave-lengths of 3·7 m and 7·9 m; a small sunspot interfered with the observations on 1·4 m.

The results obtained (**5**) were quite unlike those predicted from a simple model of the corona; no sharp reduction of intensity occurred, but a smooth "eclipsing curve" was observed on both wave-lengths. The amplitude of the interference pattern produced by the radio star was appreciably reduced even when the separation was greater than 10 $R_\odot$, and at the closest approach fell to about 20 per cent.

It seems probable that the effects observed must be accounted for in terms of scattering of the radio waves by irregular structure in the outermost layers of the corona.

1 (*d*) *The "emission polar diagram" of sunspots.*—A correlogram analysis has been made of the observations of solar radiation obtained during the past five

years on wave-lengths of 1·7 m and 3·7 m, and for one year on 60 cm; this analysis has been made to determine the mean curve of the variation of intensity with the angle between the line of sight and the radius to the visible spot. The total angular widths (to half intensity) of the "emission polar diagram" derived in this way are:

$$36^\circ \text{ at } 60\,\text{cm}; \quad 20^\circ \text{ at } 1{\cdot}7\,\text{m}; \quad 15^\circ \text{ at } 3{\cdot}7\,\text{m}.$$

1 (*e*) *Interferometric measurements of localized sources on the Sun.*—Further observations have been made at wave-lengths of 1·4 m and 3·7 m, using interferometers of large resolving power, to observe the apparent movements of the sources associated with sunspot activity.

Attempts have been made to derive the heights of the sources in the corona by observations of the day-to-day movement caused by the solar rotation; large variations in the apparent heights have been found and it seems probable that the results are confused by serious refraction effects caused by non-uniformity of the electron density above the spot.

Observations have also been made of the rapid fluctuations of the apparent position of the sources; on some occasions the movements are only of the order of 1 second of arc, whilst at other times movements as great as 1 minute of arc have been found.

2. *Observations of radio stars*

2 (*a*) *Identification of two intense radio stars.*—Following the accurate determinations of the positions of some of the most intense radio stars (**6**), Baade and Minkowski (**7**) have identified two of them with previously unrecognized objects. The intense source in Cassiopeia corresponds with a diffuse nebulosity in our galaxy in which remarkable filaments having large internal velocities can be seen. The source in Cygnus corresponds with a peculiar extragalactic body showing intense emission lines, which appears to be two extragalactic nebulae in collision.

Apart from the great importance of these identifications from the point of view of theories of the emission from radio stars, they are likely to prove most valuable in further positional observations. There are difficulties in measuring the collimation error and other positional errors of the larger radio interferometers which will be necessary for the accurate determination of the positions of weaker sources; the presence of two intense sources whose positions are known will enable the errors to be found directly.

2 (*b*) *Measurement of the angular diameters of radio stars.*—A new application of the phase-switching interferometer for measuring the angular diameter of a source has been devised (**8, 9**). In this method, which is based on a comparison of the "visibility" of the interference pattern with two different apertures, two fixed aerials are used alternatively in conjunction with a third one; by altering the position of the third aerial, whose gain does not have to be accurately stabilized, a curve showing the variation of "visibility" with aperture can be obtained.

Using this method, observations of the intense radio stars in Cassiopeia and Cygnus have been made. The maximum aperture available was insufficient to derive the complete distribution of "brightness" across the sources, but on the assumption that they were circular and of uniform "brightness" the deduced diameters were $5'{\cdot}5 \pm 0'{\cdot}2$ and $3'{\cdot}6 \pm 0'{\cdot}3$ respectively. These results have provided additional confirmation of the identifications made by Baade and Minkowski.

3. *Radio observations of the H II regions*

3 (*a*) *The integrated effect.*—Observations have been made to determine the effect of the ionized hydrogen regions on the radio emission from the galaxy. Since both interstellar hydrogen and early-type stars show strong galactic concentration, the effect is only likely to be important within a few degrees of the galactic equator (**10**). At long wave-lengths, where the "brightness temperature" of the general galactic radiation exceeds the kinetic temperature of the interstellar hydrogen, the absorption by the hydrogen will exceed its emission, and a "dark" strip is to be expected along the galactic equator; at wave-lengths shorter than about 5 m, this strip should appear in emission.

Previous surveys of galactic radiation have used insufficient resolving power to detect the presence of such a strip; a variable-aperture interferometer of large resolving power has therefore been used to obtain a detailed measurement of the distribution of brightness near the galactic plane (**11**). Observations were made at wave-lengths of 1·4 m and 3·7 m and in each case a bright strip about 2° wide was observed, superimposed on the general radiation. Some observations with somewhat smaller resolving power were also made at a wave-length of 7·9 m. By comparing the intensity at different wave-lengths it is possible to derive both the effective density in the H II regions and the average kinetic temperature. The results have suggested that the temperature exceeds 18 000 deg.

Observations at different galactic longitudes have also suggested that the distribution of the H II regions is more concentrated towards the centre of the galaxy than in either of the models suggested by Westerhout and Oort.

3 (*b*) *An attempt to observe the radio emission from the Orion nebula.*—It has been suggested (**12, 13**) that for wave-lengths of about 1 m the optical depth of the central regions of the Orion nebula should be large and that it should be appreciable over an angular diameter as great as $\frac{1}{2}°$.

Observations have been made at a wave-length of 1·4 m, but no source was found having an intensity of the order of magnitude expected. If the kinetic temperature is assumed to be 10 000 deg., these results suggest that the angular diameter over which the optical depth at 1·4 m is appreciable must be less than about 10 minutes of arc.

4. *New radio telescope*

A new interferometric radio telescope having considerably greater gain than earlier systems has been completed. The construction of the individual aerials differs from previous instruments in that a line source is placed at the focus of a cylindrical parabola; the total reflector area is about 4 700 m^2. This method of construction allows a great simplification of the structure as compared with paraboloidal reflectors of comparable area.

The main purpose of the new instrument is to allow a greater number of radio stars to be located. It should also be possible to improve the accuracy of the positions of many of the present known sources; it may then become possible to identify more of them with visible objects.

References

(1) P. A. O'Brien, *M.N.*, **113,** No. 5, 1953.
(2) C. J. Bell (in preparation).
(3) P. A. O'Brien and C. J. Bell (in preparation).
(4) K. E. Machin and F. G. Smith, *Nature*, **168,** 599, 1951.

(5) K. E. Machin and F. G. Smith, *Nature*, **170**, 319, 1952.
(6) F. G. Smith, *Nature*, **168**, 555, 1951.
(7) W. Baade and R. Minkowski (in preparation).
(8) F. G. Smith, *Proc. Phys. Soc.* B, **65**, 971, 1952.
(9) F. G. Smith, *Nature*, **170**, 1065, 1952.
(10) G. Westerhout and J. H. Oort, *B.A.N.*, **11**, 323, 1951.
(11) P. A. G. Scheuer and M. Ryle, *M.N.*, **113**, 3, 1953.
(12) A. Unsöld, *Zeits. f. Astrophys*, **26**, 187, 1949.
(13) A. Unsöld, VIIIth General Assembly of I.A.U., Rome, 1952.

University Observatory, Glasgow

(*Director, Professor W. M. Smart*)

During the year the following papers, to which reference was made in the report for 1951, have been published in *Monthly Notices*: "Star-streaming from the proper motions of the Boss *General Catalogue*" (**112**, 3) by Dr T. R. Tannahill, and "Models for unmixed stars" (**112**, 484) by Mr A. E. Roy.

Dr P. A. Sweet and Mr Roy have been investigating certain features associated with rotating stars. The high rates of rotation found in early-type stars will have a marked effect on their luminosities and effective temperatures as compared with those to be expected from non-rotating models. It is clear that, for given mass, the luminosities and effective temperatures decrease with increasing rotation rate; the extent of the changes, however, is difficult to assess without a detailed knowledge of the structure of a rotating star. Dr Sweet, in working on this problem, has been using a method of successive perturbations of a standard model. The numerical work arising from the theory is lengthy and exacting but this part of the work is being tackled successfully by Mr Roy; the first-order theory is now almost complete and the results are to be submitted shortly to the Society.

Mr D. G. Ewart has been engaged since October in preparing for analysis the detailed statistics relating to the proper motions of the faint stars (magnitudes approximately from 9·5 to 13·0) of the second *Cape Catalogue* (1939).

Dr Sweet left at the end of September to take the post of Assistant Director of the University of London Observatory; he has been succeeded by Mr M. W. Ovenden.

A large number of members of the University and of various societies have visited the Observatory on Thursday evenings during the two winter terms.

Imperial College Observatory, South Kensington, London

(*Director, Assistant-Professor R. W. B. Pearse*)

The construction of a high-temperature carbon-tube vacuum furnace has been completed. This will be used to extend studies of the absorption spectra of metal vapours in atmospheres of hydrogen and helium in the ultra-violet and vacuum ultra-violet regions, already begun by Mr W. R. S. Garton, to many more elements. Electrical recording equipment is being set up for the measurement of intensities in spectra. The theoretical studies of the intensity distribution in molecular band systems carried out by Dr M. Pillow need supplementing by more accurate experimental observations. Investigation of the broadening of lines of ionized oxygen, nitrogen, carbon, argon and magnesium in low pressure electrical discharges begun by Dr R. S. Narayan has been continued.

The Director attended the General Assembly of the International Astronomical Union and the meeting of the Joint Commission on Spectroscopy in Rome in 1952 September.

University of London Observatory

(*Director, Professor C. W. Allen*)

Parallax.—Observations have been restricted to those stars that show promise of being finished in 1953 or 1954. 3 stars have been measured, there are 5 ready to measure, and 14 on the observing programme. 21 parallax plates have been obtained.

Star clusters.—36 photographs of star clusters and fields in red and photographic wave-lengths have been obtained for the determination of colour-magnitude arrays. The observations are directed towards those objects that are not clearly of open or globular type. A preliminary result by Wang shows that NGC 6811 has a typical open cluster array.

Stellar spectra.—A study of the spectrum of the peculiar A star HD 50169 has been made by Brewer from 8 spectra borrowed from the Mount Wilson Observatory. Garstang has begun a spectroscopic analysis from red region plates taken at the McDonald Observatory.

Use of instruments.—The Radcliffe 24-inch refractor has been used on 59 nights for parallax and cluster work, the Wilson 24-inch reflector on 7 nights for spectroscopy at the Cassegrain focus or direct photography at the Newtonian focus, and the smaller instruments for students and visitors.

Theoretical work and analysis.—An analysis of the world distribution of diurnal variations of the F2 ionospheric region has been made by the Director. Sweet has made numerical calculations in connection with the structure of rotating stars. Garstang has made further calculations on line strengths in intermediate coupling.

Publications.—During 1952: C. W. Allen, "The Framework of Astronomy"—Inaugural lecture at the University College, London.

Staff and students.—Dr P. A. Sweet was appointed as Assistant Director in October and Mr R. H. Garstang as lecturer in September. Mr K. R. W. Brewer completed his M.Sc. course in July and has gone to Canberra. Mr S. K. Wang left in December to return to China. Mr V. C. Reddish commenced postgraduate work in October. Mr C. R. Spratt and Mr T. Kiang remain on the staff.

Since October there have been eight undergraduate students taking either regular lecture courses or practical astronomy.

New building.—The Radcliffe Dome was piled and underpinned during September and October. The new Office building was commenced in October and is expected to be ready for use by about 1953 March.

Visitors.—There were 374 visitors to the Observatory during 1952.

Ministry of Supply, Radar Research and Development Establishment, Malvern

A new research group has been formed within the Ministry of Supply, Radar Research and Development Establishment, Malvern, to carry out work on fundamental research problems under the direction of Dr J. S. Hey, and radio-astronomy is included in the programme.

Owing to lack of staff only a very limited effort is available as yet. The work so far has been mainly concerned with an analysis of 4-metre radio bursts in relation to solar flares and geophysical effects by Dr J. S. Hey which has been published in *R.R.D.E. Report* 372, and the development of a radiometer at 10 cm wave-length by Mr V. A. Hughes.

Jodrell Bank Experimental Station, University of Manchester

(*Director, Professor A. C. B. Lovell*)

The radio telescope.—In April it was announced that the Nuffield Foundation and the Department of Scientific and Industrial Research had agreed to share the cost of the proposed 250-ft. steerable radio telescope. The work on the foundations started in September and by the end of the year 108 of the 152 reinforced concrete piles had been completed. These reach to the Keuper marl at a depth of 50 to 90 ft. in order to support the railway track on which the instrument rotates. Good progress has also been made with the central thrust block on which the instrument pivots. The total weight of concrete and steel in the foundations is about 2 500 tons and it is expected that this stage of the work will be completed by the early summer 1953. The consulting engineers have made excellent progress with many of the details of the rotating structure, and the drawings for the main steel erection are in the hands of the steel contractors. The extension to the power house should also be completed in the spring of 1953. Two general accounts of the instrument and its proposed programme of work have been published (**1, 2**).

Extra-galactic radio emissions.—The programme of detecting the radio emission from extra-galactic nebulae with the 218-ft. fixed paraboloid has been continued (**3**). The observations have been extended to one faint cluster of nebulae in Ursa Major and to a spiral nebula (NGC 2841). The total number of individual extra-galactic nebulae so far observed is five, and the results suggest that for these nebulae the ratio of radio flux to light flux is constant. It is intended to extend these measurements to all the bright extra-galactic nebulae in the field of view of the 218-ft. paraboloid.

Analysis of galactic radio emissions.—The major part of the field of view of the 218-ft. paraboloid has now been surveyed at 158 Mc/s. The isophotes of a strip 28 degrees wide centred on the Milky Way, and extending from Cygnus to Auriga, have been plotted (**4**). An analysis has been made of all the localized sources so far detected in the survey (**5**). This analysis shows that the intense radio sources are concentrated into a narrow strip along the galactic plane. The fainter sources do not show this concentration. This result indicates that there are at least two populations of radio sources. The intense sources appear to belong to a rare class of object which lies within the Galaxy and which is concentrated close to the galactic plane. The weak sources appear to be distributed more nearly isotropically, and as yet there is no evidence to show whether the majority are inside or outside the Galaxy.

A special study has been made of the position of Tycho Brahe's supernova of A.D. 1572 (**6**). This lies close to the intense radio source in Cassiopeia and the measurements therefore present special difficulties. By means of the 218-ft. paraboloid, employed as an interferometer in conjunction with an auxiliary aerial, it has been shown that there is a radio source whose coordinates agree with

those of the supernova within the limits of experimental error. The discovery of a source in the position of this supernova (1572) supports the conclusion, originally based only on the observation of a source in the position of the supernova of 1054 (Crab Nebula), that the remnant of a supernova is a source of intense radio-frequency radiation.

Diameter of the radio stars.—A completely new type of interferometer has been developed for measuring the apparent angular diameter of the radio sources. Following successful tests of a model in the previous year a full-scale version has now been built. In its present form this instrument is intended only for use on the two most intense radio sources (Cygnus I and Cassiopeia I). It is capable of operating with extremely long baselines and was designed on the assumption that the angular diameter of the radio stars might be anywhere between the known limit of 6′ and diameters of the order of one second of arc or less.

In the summer of 1952 the instrument was used to observe the sources in Cygnus and Cassiopeia using four different baselines. The results of these measurements (**7**) show that the source in Cygnus is an elongated object. Its angular size extends from about 35 seconds of arc to 2½ minutes of arc and its major axis is approximately at 90° to the celestial meridian. The source in Cassiopeia is roughly symmetrical and has an angular size of about 4 minutes of arc. These measurements show that the radio sources have angular diameters several thousand times greater than the visible stars and that they cannot therefore be identified with bodies of stellar dimensions.

The measurements with this interferometer are being continued and it is hoped to make measurements with several different baselines. By this means it may be possible to build up an accurate picture of the size and shape of the radio sources together with the distribution of intensity across their disks.

The scintillation of the radio stars.—The measurement of F region ionospheric winds by recording the scintillations of a radio star at triangularly spaced receiving equipments (**8**) has been continued, and the station is now participating in a series of International Ionospheric Wind measurements. It has been found that the F region wind speeds are roughly proportional to the geomagnetic K index (**9**). The effect of aurorae on the scintillation characteristics has also been investigated (**9**). A further experiment, in which the scintillation of a radio star was observed simultaneously on two different frequencies (**10**) has shown that there is considerable correlation between the fluctuations on 81·5 Mc/s and 118 Mc/s and that the degree of correlation is largely independent of the fluctuation amplitude, elevation of the source and speed of fading.

1 420 Mc/s receiver for interstellar hydrogen line measurements.—A receiver is being built to investigate the 1 420 Mc/s ($\lambda = 21$ cm) interstellar hydrogen line. It is proposed to use the present 30-ft. aperture paraboloid as aerial, and the modifications of surface mesh and steering mechanism, required to make this aerial suitable for use on the new frequency, are about to be made.

Solar radio emission.—The monitoring programme of solar radiation on 3·7 m has been continued and a spectrohelioscope, the gift of Captain G. T. Smith-Clarke of Coventry, is being erected. The records of the variation in the east–west component of the Earth's magnetic field have now been taken for 18 months with an electronic fluxgate equipment; the information contained in these records is at present being correlated with the international K-figures

of geomagnetic activity. The solar and magnetic observations are providing valuable data for the radio-star scintillation and auroral research programmes.

Auroral observations.—The observation of aurorae on the meteor survey equipment has continued. The number of occasions on which aurorae have been observed is small, owing to the approaching minimum in the sunspot cycle, and no further work on the 27-day recurrence period previously noted has been possible.

The meteor survey.—The continuous meteor survey has continued without interruption throughout 1952. Radiant positions have been obtained for all the major meteor streams. Velocity measurements and orbits were again obtained for the Arietid, ζ Perseid and β Taurid daytime streams (**11**) and for the Quadrantid stream in 1952, confirming previous results (**12**). The orbit of the δ Aquarid stream was obtained for the first time (**13**). Velocity measurements obtained for Bečvář's meteor stream in 1951 December were insufficient to justify the calculation of an elliptical orbit.

The observations of sporadic meteor rates and radiants between 1949 October and 1951 September have now been analysed for publication (**14**). Most sporadic meteors are found to be moving in orbits near the plane of the ecliptic, with direct motion.

Sporadic meteor velocities.—The work on the velocities of sporadic meteors was continued in the autumn of 1951 on a fainter magnitude group than the previous experiments. A total of 960 meteors in the magnitude range $+3$ to $+9$ have now been measured, and the results show that the majority of these meteors move in short-period orbits. There is no evidence of an appreciable hyperbolic component and no change of velocity distribution with magnitude (**15**). A theoretical discussion of the velocity distributions has been given by Clegg (**16**).

Meteor physics. Theoretical.—A comprehensive theory of the scattering of radio waves from meteor trails has been developed. The dependence of the important echo characteristics (amplitude–time variation, duration, etc.) on the polarization of the incident wave, the electron line density in the meteor trail, and on the atmospheric pressure at the level where the ionization is occurring has been predicted. Using the above theory of scattering with established theories of meteoric ionization, the expected height distribution of meteor echoes has been evaluated as a function of the mass distribution of the incident meteor and the properties of the upper atmosphere.

Meteor physics. Experimental.—Experiments with an equipment designed to radiate electromagnetic waves polarized transverse and parallel, respectively, to the meteor trails have confirmed the existence of enhanced scattering with transverse polarization. The magnitude of the effect is in good agreement with theory, as is also the dependence of echo amplitude on the electron line density in the meteor trail (**17**). Measurements of the height distribution of meteor echoes obtained during the major meteor showers have continued and the height distributions obtained from selected velocity groups of sporadic meteors are being studied. These results are being analysed in the light of the theory of the height distribution leading to a determination of atmospheric pressure as a function of height over the range 80–100 km, of the mass distribution of the incident meteors, and of the total rate of meteoric ionization as a function of height.

The electron densities in meteor trails.—As a result of recent theoretical and experimental work it has been possible to revise previous estimates of electron line densities in the trails of visual meteors (**18**). Using experimental results in which visual meteor brightness is correlated with radio echo duration together with the theory relating echo duration to electron line density, it has been found that the linear electron density produced by a meteor of given brightness is some two orders of magnitude greater than previously estimated. This has been attributed largely to an underestimate by earlier workers of the ionizing efficiencies of evaporated meteor atoms, coupled with an over-estimate of the luminous efficiencies.

Winds in the meteor region.—The investigation of uniform and turbulent winds in the region 80–100 km above the Earth, from observations of radio echoes from meteor trails, has continued (**19**). Work is in progress on new experimental techniques to enable much greater resolving power to be obtained. It is hoped to make a detailed survey of the variation of wind velocity with height throughout the meteor region, and to compare these results with winds in the F region, measured simultaneously from the scintillations of radio stars.

Long-pulse equipment.—The equipment is now operating with a transmitter power of 3 kw and pulse length 20 milliseconds, on a frequency of 120 Mc/s. The receiver bandwidth is 40 c/s. Preliminary observations indicate that the echo signal from the Moon is at least 5 dB below receiver noise level, which is considerably less than predicted. Improvements are being made to the transmission line and aerials in order to reduce losses which were revealed by recent tests.

Publications.—The programme of publications as outlined in the previous report has commenced. The first number (**12**) of the *Jodrell Bank Annals* was issued in 1952 and the second number (**10, 11, 13**) will be issued early in 1953. In addition to the publications mentioned above, the 1951 Norman Lockyer lecture (**20**) has been issued as a Jodrell Bank Reprint (No. 66).

References

(1) A. C. B. Lovell, *Times Science Review*, November 1952.
(2) A. C. B. Lovell, *London Calling*, 1952 August 21.
(3) R. Hanbury Brown and C. Hazard, to be published.
(4) R. Hanbury Brown and C. Hazard, *M.N.*, **113,** 109, 1953.
(5) R. Hanbury Brown and C. Hazard, *M.N.*, **113,** 123, 1953.
(6) R. Hanbury Brown and C. Hazard, *Nature*, **170,** 364, 1952.
(7) R. Hanbury Brown, R. C. Jennison and M. K. Das Gupta, *Nature*, **170,** 1061, 1952.
(8) A. Maxwell and C. G. Little, *Nature*, **169,** 746, 1952.
(9) C. G. Little and A. Maxwell, *J. Atmos. Terr. Phys.*, **2,** 356, 1952.
(10) K. Burrows and C. G. Little, *Jodrell Bank Annals*, **1,** 29, 1952.
(11) Mary Almond, K. Bullough and G. S. Hawkins, *Jodrell Bank Annals*, **1,** 13, 1952.
(12) G. S. Hawkins and Mary Almond, *Jodrell Bank Annals*, **1,** 2, 1952.
(13) Mary Almond, *Jodrell Bank Annals*, **1,** 22, 1952.
(14) G. S. Hawkins and A. Aspinall (in preparation).
(15) Mary Almond, J. G. Davies and A. C. B. Lovell, *M.N.*, in publication.
(16) J. A. Clegg, *M.N.*, **112,** 399, 1952.
(17) R. L. Closs, J. A. Clegg and T. R. Kaiser, *Phil. Mag.*, **44,** 313, 1953.
(18) J. S. Greenhow and G. S. Hawkins, *Nature*, **170,** 355, 1952.
(19) J. S. Greenhow, *J. Atmos. Terr. Phys.*, **2,** 282, 1952.
(20) A. C. B. Lovell, *The Advancement of Science* (Brit. Ass.), **8,** 351, 1952.

University Observatory, Oxford

(Director, Professor H. H. Plaskett)

New solar telescope and spectroscope.—The tower and tunnel to house an *f*/70 telescope of 117 feet focal length and its accompanying spectroscope were largely completed by the end of 1952. Grubb, Parsons erected the dome in August and the telescope in December. The Cassegrain and the second Coudé mirrors, on which some further work has to be done, will with the other mirrors probably be installed in the telescope in the spring. Continued difficulty in getting the optical parts of the spectroscope has been experienced, and though the prospects are now slightly more promising it is unlikely that the spectroscope can be ready for operation before the middle of 1954.

Determination of solar and laboratory wave-lengths.—The interferometric determination of the wave-lengths of solar and vacuum-arc lines of Fe and Mn in the regions of 5080 A and 6020 A was completed by Miss Adam during the year, and the results communicated to the Society (*M.N.*, **112,** 546). These wave-lengths have been determined from a direct comparison with the red Cd line and as secondary standards should be relatively free from systematic error. The observed red-shift is 0·0093 A at 5080 A and 0·0065 A at 6020 A, that is 86·9 and 51·6 per cent respectively of the predicted relativity shift. No satisfactory interpretation of these observed red-shifts has yet been obtained. In order to find the wave-length dependence of the red-shift Miss Adam made further interferometric observations of Ca and Fe lines in the regions 6490 A and 6570 A during July and August.

Motions in the solar photosphere.—Mr Kinman's determination of the Evershed effect in the penumbra and adjacent photosphere of sunspot Mt. Wilson No. 9987 was communicated to the Society during the year (*M.N.*, **112,** 425). The investigation, which is based on the sight-line velocities at 237 points, shows clearly that the motion consists of a steady radial flow increasing from 1 km sec^{-1} at the edge of the umbra to a maximum of 2 km sec^{-1} in the middle of the penumbra and finally falling to zero far out in the adjacent photosphere. From the observed speed of flow and the known variation of temperature across the penumbra Mr Kinman has been able to calculate the quantity of heat absorbed per unit mass per second following the motion, and to show that its value is not inconsistent with other observed and inferred properties of spots. Further spectroscopic observations were made in May, June and November in an attempt to find the speed of the flow as a function of the size of the umbra.

Using much the same observational technique (*M.N.*, **112,** 414) Miss A. B. Hart has continued her investigation of the equatorial solar rotation. Further observations were made in April and September, and the measurement of 334 sight-line velocities has now been completed. The discussion of these measures is well advanced and Miss Hart hopes to communicate a paper on her results during 1953.

Other solar investigations.—Mr J. B. Sykes has communicated to the Society a new and elegant method for the solution of the integral equation of limb-darkening, and has used the method to find the source function from the mean of five separate determinations of limb-darkening. In October Mr R. J. Bray commenced an observational investigation of the profiles of the Na lines 5683, 5688, 5890 and 5896 A. At the close of the observational season in November

he commenced a determination of the apparatus function of the spectroscope at these wave-lengths.

Stellar work.—The Radcliffe Travelling Fellow, Mr D. W. N. Stibbs, during the tenure of his Fellowship in Pretoria, obtained and measured 860 spectra of 55 southern Cepheid variables, in addition to obtaining and measuring 87 spectra of 18 standard stars. Since his arrival in Oxford at the beginning of October he has made good progress in the reduction of these spectra.

In addition to his work on comets Dr Merton has developed and communicated to the Society a new method for finding the spherical coordinates of an object from its measured distances from three nearby standard stars. The method, analogous to the position-line method in navigation, has the dual advantage of requiring a measuring machine with only a short screw and of being readily applicable to photographic telescopes with curved fields.

University Observatory, St. Andrews

(*Director, Professor E. Finlay-Freundlich*)

Staff.—Dr A. Jarrett received the Ph.D. degree on a thesis on "Investigations concerning semi-reflecting films with special reference to interferometry".

Mr D. Mugglestone accepted an appointment at the University College of Jamaica, but continues his astrophysical research under supervision from St. Andrews.

Mr Angus MacAulay joined the Observatory staff as a research student and is engaged in experimental research under the supervision of Dr A. Jarrett.

Dr R. Kurth, Berne, joined the Department on 1952 October 1, with a D.S.I.R. Senior Award and is engaged on theoretical research concerning the study of star systems. He gave a series of lectures on this subject.

Scientific research.—The regular observational work with the 20-inch Schmidt–Cassegrain Telescope was as follows:

(*a*) In connection with Miss Middlehurst's photometric observations, various colour filters from Schott (Jena) were obtained and are being tested. Work has also begun on the construction of an iris diaphragm photometer with the cooperation of the Physics Department.

(*b*) During the summer months, while no observations were made, Dr Cisar, in collaboration with Dr Linfoot, continued the microphotographic investigation of the image properties of the 20-inch Schmidt–Cassegrain optical system with an improved set-up. In the course of these experiments it was realized that the Schmidt plate was not yet in its optimal position. After this correction, which produced a visible improvement of the optical images, an extensive amount of microphotographic films was obtained. The result of this investigation has not yet been worked out. When the observational season started, Dr Cisar began with an extensive programme of exposures of star fields which, according to radio astronomical observations at Jodrell Bank, Manchester, emit conspicuous long-wave radiation.

(*c*) T. Slebarski continued his astrographic investigation; Dr Jarrett's work on multi-layer coatings was completed and formed the thesis for his Ph.D. degree. A paper giving the main results is ready for publication.

For the coming eclipse in 1954, Dr Jarrett is preparing, in collaboration with Dr H. v. Klüber, Cambridge, a Fabry–Perot interferometer equipped with

multi-layer coatings, to analyse the corona spectrum. Preparatory experiments have been going on for a while. In addition, research work has started on an improved scheme of photographic recording with the telescope.

The preparations for the eclipse expedition to redetermine the relativistic light deflection at the coming solar eclipse in Sweden in 1954 are proceeding.

Workshop.—The dome containing the 20-inch Schmidt–Cassegrain Telescope was electrified, so that the observer can turn the dome while guiding on a star.

Regarding the 38-inch Schmidt–Cassegrain Telescope under construction, the two mirrors, i.e. the 38-inch primary and the 19-inch secondary, are completed. Work on the disk of U.V. glass for the Schmidt plate has started.

The mechanical workshop is busy with the construction of the floating system for the primary mirror.

Publications.—E. Finlay-Freundlich, "Der heutige Stand der Prufung der Rel. Theorie", *Wiss. Annalen der Deutschen Akademie der Wissenschaften.* A. Jarrett, two notes to *Nature* on multi-layer coatings.

Norman Lockyer Observatory of the University College of the South West
(*Director, Mr D. L. Edwards*)

Repairs to the domes have now been completed and the telescopes are again available for night work, though weather during the year has been exceptionally poor. The main programme continues to be concerned with the relative gradients of early-type stars and allied problems. In addition, the work on galactic clusters which, owing to shortage of staff, has been in abeyance since the departure of Dr G. Alter, is being continued by Mr S. N. Svolopoulos of the National Observatory of Athens who is working as a research student. Results for a number of clusters, treated in a similar manner to those in Alter's survey, are nearing completion.

The spectrophotometric programme of observations of the twilight sky referred to in last year's report has been continued. A fast 2-prism spectrograph has been completed in the Observatory workshop, and will be used to search for possible anomalous polarization effects in the plane of the Earth's magnetic field at times of solar and geomagnetic disturbances.

The Observatory has suffered a great loss in the death of Sir Richard Gregory, who had been very actively interested in the Observatory since its foundation. He was for many years Chairman of the Council and also, after the death of Sir Robert Mond, of the Corporation as well. In addition to many other helpful activities he took a prominent part in arranging the transfer of the Observatory to the University College of the South West, of which College he was made a Vice-President. The death of Professor F. H. Newman will also be severely felt. He was, at that time, acting Principal of the College and a valued member of the Observatory Council and Research Committee.

Dunsink Observatory
(*Director, Professor H. A. Brück*)

Equipment.—A 28-inch mirror, the property of the late Mr J. H. Reynolds, has been purchased, which, when mounted, will replace the present 15-inch mirror for photoelectric observations.

The photoelectric installation has been further improved, and following successful tests, suitable equipment for the simultaneous photometry of two stars is now being constructed.

Through the kindness of Professor H. H. Plaskett, a plate-measuring machine has been obtained on loan from the Oxford Observatory. It is to be used for preliminary measurement of the plates which have been secured with the Armagh–Dunsink–Harvard Telescope. Their photometric analysis will be carried out in due course with an iris plate photometer which has been ordered from the Eichner Instrument Company, Clifton, N.J.

Stellar work.—Photoelectric observations of stars and of the minor planet Vesta have been continued by Mr Argue. The results, which afforded a test of the E.M.I. type 5060 photomultiplier, are being printed in the *Proceedings of the Royal Irish Academy* (Dunsink Contribution, No. 6). A more detailed account of his work has been submitted by Mr Argue to Trinity College, Dublin, as a thesis for the M.Sc. degree.

An account of experiments on the determination of stellar magnitudes by the "double-telescope method" has been given by Mr Argue and Dr Butler in *The Observatory*.

A method has been evolved by Dr Butler which promises to be of value for the practical solution of the problem of star counting. It is based on a photoelectric analysis of pairs of plates and appears capable of yielding figures for the numbers of stars of different magnitude without actual counts.

Solar work.—An expedition to Khartoum was planned and carried out in close collaboration with Dr D. A. Jackson for the observation of the solar eclipse of February 25. It was intended to test whether line widths in the spectrum of the chromosphere can be measured interferometrically. A quartz Fabry–Perot etalon together with a Hilger quartz spectrograph were used. The solar image, one inch in diameter, was produced by a 15-inch mirror which was fed by a coelostat. Flash spectra were secured, one each at second and third contacts, and also spectra of a helium comparison source which were taken immediately before and after totality. The reduction of the observations has shown that interferometric measurements of line widths in the flash spectrum are practicable, and it is intended to apply the same method with larger instruments than were available in Khartoum, on the occasion of the next eclipse in 1954. The results of the Khartoum observations are being printed in the *Proceedings of the Royal Society* (Contribution, No. 7).

The solar installation at Dunsink has been used for photographic and photoelectric work. It is proposed to take up again the programme of photoelectric scanning of the solar spectrum for the measurement of profiles of Fraunhofer lines.

Miscellaneous.—Mr O'Connor has completed and published in the *Proceedings of the Royal Irish Academy* a list of all solar eclipses which have been visible in Ireland between A.D. 400 and 1000 with an appendix pertaining to conditions at Iona (Contribution, No. 5).

The Rome Assembly of the International Astronomical Union has been attended by four members of the staff, and an invitation to hold the next Assembly in 1955 in Dublin has been issued at that conference. Professor and Mrs Brück also took part in the Convegno "Volta" on solar physics which had been arranged by the Italian National Academy of the Lincei for the time after the I.A.U. meeting.

Dominion Observatory, Ottawa, Canada

(*Director, Dr C. S. Beals*)

Positional astronomy.—Meridian Circle observations were continued on a list of stars comprising those in use or needed with photographic zenith tubes at Richmond, U.S.A., Greenwich, and at Ottawa. Approximately 6000 observations were taken during the year. The computations for 1950 were completed to mean place and listed at the University of Toronto Computation Centre, and the 1951 results are being finished there at the present time. Results of observations taken 1923–35 were published during the year. These include observations of the Sun, Mercury, Venus and a catalogue of 1589 stars along with corrections to the Boss *G.C.* and FK3. There still remains a series of observations taken 1935 to 1950 to be completed.

Observations with the broken-type transit for time were discontinued in the early part of the year after the results with the 10-inch P.Z.T. proved to give smoother results. Certain adjustments had to be made during the extremely cold weather to assure automatic control. Scatter of the individual star results was reduced by greater restraint of the plate and plate holder. A new measuring engine has been designed and is being constructed in the observatory machine shop. At present a Toepfer machine is being used to measure the plates and improved results are expected with the new machine.

Muirhead time-signal machines control the signals broadcast continuously over station CHU on 3330 kc/s, 7335 kc/s and 14670 kc/s, and once daily on the C.B.C. network. The new 3000-watt transmitter is not yet in operation but alterations to the building for housing it are nearly completed. The main clocks comprise three crystal clocks and the Shortt Free Pendulum. A second Western Electric Frequency Standard is on order.

The older time-signal machines continue to control time signals sent to the C.N. and the C.P. railways, the master clocks in government buildings, minute dials and seismograph instruments.

Stellar physics.—The 20-foot solar grating spectrograph was used in combination with the 80-foot horizontal solar telescope for a detailed study of the infra-red solar spectrum in the regions of the fundamental and first overtone bands of carbon monoxide, at 4·7 μ and 2·3 μ respectively. In the first region tracings were obtained using a 5000 line/inch grating and a lead telluride detector. In the second region a 14000 line/inch grating and a lead sulphide detector were employed. By comparison with spectra obtained in the laboratory the abundances of carbon monoxide in the atmosphere of the Earth and Sun have been calculated.

The theoretical studies of the atmosphere of Be stars were continued. The emission-line profiles were interpreted in terms of a scattering mechanism and the state of the envelope necessary to produce them was investigated. The theory of light was studied from the relativistic standpoint, and a union of light considered as gravitational radiation with light treated as electromagnetic radiation was established.

Two Super-Schmidt meteor cameras, purchased from the Perkin–Elmer Corp. at Norwalk, Conn., were installed at the meteor observatories at Meanook and Newbrook, Alberta, during the summer of 1952. These cameras were designed by Dr James Baker and combined an aperture of 12 inches with a focal length of 8 inches, covering a circular area in the sky 52 degrees in diameter. Their

optical performance has proved to be excellent and the evidence secured to date indicates that they will photograph meteors down to magnitudes between 3 and 4 visual. Six new meteor spectrographs, equipped with Bausch and Lomb transmission gratings, were also put in operation at Ottawa and Meanook during this last summer. Two particularly fine spectra of Perseid fireballs and their trains were secured with these instruments.

Observations of the Lyrid, Delta Aquarid, Perseid, Orionid and Geminid meteor showers were carried out in 1952. A total of 923 exposures with meteor cameras was made in an observing time of 244 hours. In all 1 730 meteors were visually recorded.

A new Canadian meteorite, the Abee meteorite, fell just 8 miles south of the Newbrook Meteor Observatory on 1952 June 9. Observers of the detonating fireball associated with this meteorite have been interviewed in the Edmonton–Athabaska district and the object, weighing 237 lb., has been purchased for the collection of the Geological Survey of Canada.

Terrestrial magnetism.—Magnetic survey operations were carried out in Eastern Canada between latitudes N. 46° and N. 56° and longitudes W. 65° and W. 95°, and in Western Canada between latitudes N. 54° and N. 65° and longitudes W. 110° and W. 141°. Measurements of declination, inclination and force were made at seventy-two points comprising twelve exact repeat stations, forty-one in new areas, and nineteen in the close proximity of former repeat stations.

The compilation and construction of isomagnetic maps of Canada continued. Further progress was made in research dealing with certain aspects of secular change in the Earth's magnetic field deduced from Canadian data. Isogonic and isoporic lines were drawn and magnetic data supplied for 1 163 marine charts, and topographical and air navigation map sheets.

The four magnetic observatories situated at Agincourt, Ontario, at Meanook, Alberta, and at Baker Lake and Resolute Bay, Northwest Territories continued normal operations. The new non-magnetic observatory building at Meanook was equipped with a non-magnetic heating system using propane gas as fuel. Two sets of recording variometers were moved from the old to the new observatory building.

The Dominion Observatory design of a universal airborne magnetometer reached the final stage of assembly. An electrical type absolute magnetometer was designed and constructed for observatory use, with which it will be possible to measure declination, inclination, total force and the horizontal and vertical components directly and quickly.

Dr Julius Bartels, Professor of Geophysics, University of Göttingen, and Director of its Geophysical Institute, was visiting scientist with the Division of Terrestrial Magnetism during the summer.

Gravity.—During the year under review, gravimeter field work consisted chiefly of improving gravity ties between gravimeter bases used in previous years. Both automobile and aircraft transportation were used and about 300 base stations were connected. They extend from southern Quebec north-west to Lake Athabaska, a distance of nearly 2 000 miles. Pendulum bases including the national base at Ottawa were reoccupied and it is expected that the results of this season's work will provide a basis for uniform adjustment of most gravimeter work so far completed in Canada as well as for future surveys.

An observing programme to provide a line of pendulum stations suitable for gravimeter calibration over a large change in gravity and to ensure uniformity of

units throughout the gravity network of North America was initiated this year. In cooperation with the United States Coast and Geodetic Survey and the Mexican Government, the Dominion Observatory made observations, with pendulums borrowed from Cambridge University, at eight stations on a line extending from Mexico City to Winnipeg, Manitoba. The total change in gravity covered was over 3 000 milligals, and preliminary calculations, based on repeated measurements at certain stations, indicate an error of less than one milligal. Besides providing a base line for calibration purposes, the observations strengthen the ties between the national bases at Mexico City, Washington and Ottawa.

Present plans for the 1953 season include the extension of the line of base stations northward along the Alaska Highway to Fairbanks, Alaska. It is also proposed to make a connection between Ottawa and the site of the absolute gravity determination at Teddington, England.

Seismology.—Several improvements have been made in the regular network of seismograph stations maintained by this Observatory. The Halifax station has been housed in a new vault and re-instrumented with Benioff long- and short-period verticals and Sprengnether long-period horizontals. A Leet–Blumberg pen-recording seismograph has been installed at the Ottawa station and a new long-period seismograph has been added to the instruments operated at Resolute Bay.

The research energies of the Division are directed along three principal channels. The first deals with crustal studies. A detailed programme, based chiefly on rockbursts as an energy source, has been completed and papers giving the results are now in the press. An enlarged programme, intended to extend more detailed studies to other areas of the Canadian Shield, is contemplated and new instruments are being assembled for this purpose.

A second phase of research has to do with the study of local earthquakes in the Saint Lawrence Valley and in British Columbia. The studies in British Columbia are meeting with considerable success and annual publication of earthquake data is contemplated. The rockburst studies have resulted in travel-time curves appropriate to the Saint Lawrence area and a programme has been started to review the records of past earthquakes. It is hoped that seismic areas may be more closely defined than has been possible in the past.

The third project of the Division has to do with the direction of faulting in large earthquakes. During the past summer tables were produced permitting use of the core phases in these studies, and preliminary analysis was made of about thirty more earthquakes.

David Dunlap Observatory, University of Toronto

(*Director, Professor J. F. Heard*)

Radial velocities.—Observation and measurements have continued on the few uncompleted parts of the programme of 1 050 stars of type Go and later in Yale Zone 25° to 30°. Observations have been begun on a programme of high-velocity stars initiated in collaboration with Dr Nancy Roman of the Yerkes Observatory.

Orbits were determined for the spectroscopic binaries HD 164898, HD 208835, HD 40372, HD 224085 by Miss Northcott and graduate students. Observations have been obtained for studying the orbit of the hydrogen-poor star, HD 30353, and of a few other spectroscopic and eclipsing binaries of interest.

Spectrographic.—Weston observed 32 Cygni during its eclipse of 1952 December with a view to improving the elements of the orbit and studying the atmospheric effects during the partial eclipse.

Heard has made a study of the spectrum of Nova Scuti 1949, and has continued observations of Be stars.

Photometric.—Mrs Hogg discovered something over thirty new variable stars in ten globular clusters. During the summer months 215 plates were taken with the 19-inch telescope for further study of the bright, slow variables in the globular clusters on her programme.

Weston has studied the nature of the variable stars in the neighbourhood of NGC 7023 and has shown that this region resembles a T-association. He has also continued his study of the nebula itself.

Bakos has begun photoelectric observations of a small group of eclipsing variable stars.

Spectroscopic parallax.—Hossack, using an oscilloscopic microphotometer designed and built by himself, has developed a technique for classifying G and K type stars from 33 A/mm spectrograms on the Morgan Keenan Kellman system with greater precision than is possible by visual inspection.

Radio astronomy.—Williamson, collaborating with the U.S. Navy–Cornell University Radio Astronomy Project, has continued the reduction of observations of galactic radiation at 200 Mc. In the course of doing this he has studied the limitations in measuring the distribution of galactic radiation by radio telescopes and has devised a new method of reduction which is superior in speed and accuracy to methods previously used.

Equipment.—The vacuum system for the aluminizing chamber for the 74-inch mirror has been rebuilt, using an Edwards 10-inch diffusion pump, with considerable improvement in efficiency.

A 6-inch Cooke refractor formerly on the University Campus has been installed in the north dome of the Observatory administration building.

Staff.—Professor J. F. Heard was appointed Director in July.

Mr R. L. Baglow resigned as lecturer, and Mr E. B. Weston was appointed.

Publications.—Since the last report, *Pub. D.D.O.*, **1**, No. 26 and **2**, No. 1 and *Comm. D.D.O.*, Nos. 28, 29, 30 have been issued.

Dominion Astrophysical Observatory, Victoria, B.C.

(*Dr R. M. Petrie, Dominion Astrophysicist*)

Staff.—The workshop staff has been increased with the appointment of Mr A. R. Salonen, instrument maker. Dr A. McKellar is spending the academic year, on leave of absence, at the McLennan Laboratory, University of Toronto. The following persons joined the staff, temporarily, during the summer:

Professor R. J. Trumpler, University of California, Messrs J. L. Climenhaga, J. Galt, J. Maybank and J. Merner.

Professor Marshal Wrubel spent a month at the Observatory measuring line intensities in the spectrum of Procyon.

Spectroscopy.—The important eclipsing system 31 Cygni was observed during the eclipse in 1951. A. McKellar and G. J. Odgers, in collaboration with the University of Michigan astronomers, have completed a study of the

chromospheric *K*-line. They find definite evidence of sporadic and short-lived irregularities in the calcium chromosphere. The *K*-line is seen to be complex on several occasions under high dispersion.

The systems of 32 Cygni and ζ Aurigae, similar to 31 Cygni, have been studied. K. O. Wright has determined new orbital elements for 32 Cygni and obtained spectra during "atmospheric" eclipse. The composite spectrum, in the violet, has been analysed, with the conclusion that the rapid colour change may be explained by the heavy line-absorption in the spectrum of the K-type component.

A. McKellar and R. M. Petrie have completed a study of the chromospheric *K*-line during the 1950 eclipse of ζ Aurigae. Intensities and radial velocities have been measured. The variation in the calcium absorption falls between the two cases previously recognized. The velocities depart as much as 25 km/s from the ordinary orbital motion and are not explainable as rotation of the K-type atmosphere. It is considered that evidence is present of a large-scale "prominence" activity.

Spectrophotometric measures of line intensities continue. Professor Wrubel and K. O. Wright have determined new intensities in the spectrum of Procyon, dF5, using high dispersion. Curves of growth will be constructed and compared with a series of model-atmosphere results to decide upon the most appropriate model.

K. O. Wright has obtained a series of high-dispersion spectra of Capella from λ3700 to λ6700 in order to investigate the curious phenomena pointed out by Struve. In the visual region the strong lines of the primary are accompanied by secondary lines broader than those of the brighter spectrum. In the blue a few differences suggest that the fainter star is of earlier type. The spectrum in the ultra-violet appears to be peculiar but it is not yet established that the appearance does not result from very severe blending in the many-lined spectra.

Approximately fifty spectral lines in the spectrum of α Cygni have been measured by K. O. Wright with linear dispersions ranging from 2 A/mm to 23 A/mm. Generally, smaller equivalent widths are found with lower dispersions. Hδ and Hγ are asymmetrical upon the high-dispersion plates. Broad lines of the diffuse series in helium are found and C II, λ4267, has been identified, tentatively.

Absolute magnitude correlations have been extended to the B stars by R. M. Petrie. The measured absorption of Hγ is found to correlate well with the luminosity. One hundred stars drawn from galactic clusters, visual binaries and eclipsing binaries give the relation

$$M_v = -10{\cdot}96 \times 10^{-0{\cdot}145\,W},$$

where W is the equivalent width of Hγ. The system is in agreement with that of the trigonometric parallaxes and will be used in galactic studies at Victoria.

The absolute magnitudes of the O stars are being investigated. J. A. Pearce is examining the Hγ criterion in the spectrum of 800 stars. A. B. Underhill is studying the behaviour of the ultra-violet Balmer lines H9, H10, H11. It is expected that the latter lines will give the more sensitive index of luminosity but the practical advantages of Hγ require its study.

The origin of emission lines in the spectra of the long-period variables has been studied by G. J. Odgers and A. McKellar, who find that the main observed

features of the emission may be explained as a consequence of the hydrogen convective zone.

The outer layers of the early-type stars are being studied by Jean K. McDonald through the medium of model atmospheres. Hydrogen-line profiles obtained with adequate dispersion are compared with the calculated profiles. It is concluded that the currently used model-atmosphere method of computing the Hγ profile will not provide a sufficiently discriminating criterion of the absolute magnitudes of the B stars, although extension to additional models may modify this conclusion. It is proposed to attack the problem by computing a number of models with the "Ferut" electronic computer of the University of Toronto. An improved treatment of the equation of transfer in a stellar atmosphere is proposed for this work, which is being carried on by J. K. McDonald and G. J. Odgers.

Miss A. B. Underhill has continued spectroscopic studies of the "shell" stars ζ Tauri, 14 Comae and 48 Librae. The radial velocities of ζ Tauri confirm the long-period binary motion with superimposed irregularities, the latter being correlated with changes in the hydrogen absorption. The "shell" spectrum of 14 Comae shows a very low level of excitation while the underlying stellar spectrum appears to be that of an A5 giant in rapid rotation. Changes in the radial velocity and line shapes, as well as hydrogen emission, are observed in the spectrum of 48 Librae from 1950 to 1952. The underlying star is B3 but the shell spectrum indicates an excitation temperature about 9000 deg.

The analysis of the spectra of the N-type stars is being continued by A. McKellar. The unidentified bands in the blue-green and far-violet regions have been studied in collaboration with Professor P. Swings and Dr K. N. Rao.

The Swan bands in the spectra of several comets have been studied by A. McKellar and J. L. Climenhaga. The observed profiles of the bands indicate a high excitation temperature, of the order of 2500 deg. The results will appear as part of the 1952 Liège Symposium.

Stellar motions.—The main programmes have been continued. It is expected that during 1953 observations will be completed for the B stars between apparent magnitudes 7·5 and 8·6, and declinations north of +20°. The current observing season should see the completion of observations on the North Galactic Pole Cap programme.

The revision of wave-length standards for the B-type stars is virtually complete. The system is connected, through A-type stars, to the solar-type stars by the use of visual binaries and galactic clusters. It is found that laboratory wave-lengths may be adopted for a sufficient number of lines on single-prism spectrograms. Important exceptions are the diffuse triplets in helium. The new wave-length system will be used in the current programme of B stars.

A survey of the environs of the Praesepe cluster is being made by J. K. McDonald. Radial-velocity determinations may lead to the addition of members remote from the cluster centre if any such distant members exist.

Binary stars.—J. A. Pearce has continued orbital studies of early-type, massive spectroscopic binaries. Orbital elements have been determined for two massive systems HD 228854 (O6, O7) and HD 229196 (O6, O6), and for a spectroscopic binary in the Pleiades, HD 23642 (A1, A1). The binaries HD 37515 (B0, B1) and HD 37756 (B1, B1) have been re-observed and new orbits, including the secondary, have been computed.

A revised orbit, including recent observations, has been calculated for the eclipsing system 32 Cygni (gK5, B8). A spectroscopic triple system ADS 8189 has been investigated by Mrs R. W. Edmonds and R. M. Petrie. Orbital elements of the close pair were determined.

A number of visual binaries is being observed by A. B. Underhill. It is expected that the spectroscopic observations will in time combine with the visual measures to yield accurate stellar dimensions of the components.

A study of the origin and evolution of binary stars has been made by G. J. Odgers and R. Stewart (of the Pacific Naval Laboratories). This work is concerned with the dynamical properties of masses of matter of interstellar dimensions and gives a plausible account of the observed frequencies of double, triple and multiple systems. A paper on this was read before the American Physical Society.

Seismology.—Four western Canadian stations were operated during the year by W. G. Milne. Approximately 200 local earthquakes have been detected and, of these, 85 have been assigned definite epicentres. Exchange of information and routine reports of seismic activity have been maintained. Practically completed is a study of travel times and their discontinuities at epicentral distances of twenty degrees.

Instruments.—The most important event was the virtual completion of the new universal stellar spectrograph that was attached to the telescope in May. Preliminary tests as to its performance are eminently satisfactory and only minor accessories and adjustments remain to be completed.

An experimental form of an "image-converter" for infra-red spectroscopy has been constructed. Trials have shown that stellar spectra, at 10 000 A, can be obtained, and suggest that future developments now under consideration will be of great value in infra-red stellar spectroscopy. During the year a photo-electric stellar photometer was designed and constructed by P. E. Argyle and J. A. Galt. It is expected that this will be employed on eclipsing binaries and for colour measures of early-type stars.

General.—Construction was commenced upon an addition to the office building. In addition to much-needed offices, this will provide laboratory space and ample room for the library which is now quite inadequately provided for.

In June the Observatory was host at a combined meeting of the American Astronomical Society and the Astronomical Society of the Pacific. During the visit of the group a plaque in memory of Dr J. S. Plaskett was placed on the telescope and dedicated.

The following publications were issued: *Publications of the Dominion Astrophysical Observatory*, Vol. VIII, No. 15, Index; Vol. IX, Nos. 2, 3; *Contributions of the Dominion Astrophysical Observatory*, No. 25.

Union Observatory, Johannesburg

(*Director, Dr W. H. van den Bos, Union Astronomer*)

The 26½-inch refractor has been used on 187 nights for interferometer and on 56 nights for micrometer measures of double stars. The interferometer work is done by Dr Finsen, the micrometer work by Dr van den Bos, while during part of the year Dr Voûte shared in the micrometer work as a guest observer.

Plates taken with the Franklin–Adams telescope by Mr Bruwer:

Minor planets	206
Comets	46
Miscellaneous	7
Total	259 plates

Mr Johnson, who retired in 1951 December, continued his work on minor planets and took 107 plates with the Rockefeller telescope of the Leiden southern station and the Franklin–Adams telescope. He also measured and reduced a number of plates kindly taken with the ADH telescope of the Harvard Southern Station, especially for minor planets too faint to be reached with the telescopes at Johannesburg. The Franklin–Adams telescope has also been used by Mr Westerhout of Leiden Observatory.

With the 9-inch refractor, 17 occultations were observed by Mr Bruwer.

Counts of sunspots were made on 302 days.

During the year 941 visitors were admitted on 32 nights.

Members of the Transvaal Branch of the Astronomical Society of South Africa assisted in receiving the visitors.

The Time Service is operated by Messrs Hers and Seligmann.

Circulars Nos. 111 and 112 were published and distributed.

Dr Walraven was the Leiden Observer throughout the year and Mr Westerhout from Leiden Observatory worked at the Observatory from April 9 to October 26.

Astronomers Butler, Cousins, Oort, Ramberg, Stibbs, Stoy, van der Borcht and Voûte visited the Observatory.

Radcliffe Observatory, Pretoria

(*Director, Dr A. D. Thackeray, Radcliffe Observer*)

Equipment.—The 2-prism Cassegrain spectrograph has been used throughout the year as the chief accessory instrument to the 74-inch reflector. The performance of the F2 quadruplet camera is satisfactory since the separation of the components was readjusted for the photographic region by the makers, Messrs Hilger and Watts.

The Coudé secondary mirror and two flats have been received from Messrs Grubb, Parsons. These were tested on the telescope during a few nights in November and plans for a Coudé spectrograph are proceeding.

The Newtonian secondary mirror was re-aluminized during the year.

The photoelectric photometer constructed at Leiden for use at the Cassegrain focus has been delivered, together with a Brown recorder. This instrument is not yet in regular operation.

With the cooperation of the S.A. Council for Scientific and Industrial Research progress has been made with the construction of a photoelectric integrator and the redesign of the Observatory's microphotometer.

A new Hilger micrometer has been obtained for measurement of radial velocities, the Casella projection micrometer being in continual use for the same purpose.

Buildings.—A fourth house has been built in the grounds, so that it is now possible for the mechanic to reside at the Observatory. The Office building has been extended to include two extra office rooms and a basement for storage of plates. Three extra rooms for native staff have also been built.

Observations:

(*a*) *Radial velocities.*—150 southern stars, type O to B5, with unknown velocities have been observed. The observational part of this programme, which aims at 5 plates per star, is more than 75 per cent complete; the remainder of the plates are expected to be obtained during the early months of 1953. About 60 per cent of the measurement has been completed. A preliminary plot of the velocities shows that these stars (magnitude 6 to 7·5) reveal effects of galactic rotation essentially free from the systematic velocity of the Scorpio–Centaurus group. One double-line binary has been detected so far. One star with high galactic latitude, HD 214539, has the extraordinarily high velocity (apparently constant) of +325 km/sec.

As a supplement to this programme a number of southern B stars with known velocities are being re-observed, and 24 northern B stars are being observed in conjunction with the Dominion Astrophysical Observatory, Victoria. During 1953 it is planned to start a programme of 100 fainter stars, type O–B2, whose photoelectric colours have been determined by Oosterhoff.

Observations by D. W. N. Stibbs, Radcliffe Travelling Fellow, begun in 1951 June, included 860 spectra of 54 galactic Cepheids, and 84 spectra of standard stars, care being taken to secure plates at all phases of the light-curves of the Cepheids as far as possible. Measurement and reduction have reached an advanced stage. The analysis of the observations will be carried out at Oxford.

The routine programme of the Cape Observatory on radial velocities of southern stars has been continued.

Thirteen pairs of spectra of the two components of α Centauri have been measured. The difference in radial velocity has been determined accurately and in combination with the known visual orbit this yields a parallax of the system which confirms the trigonometrical value and has about the same accuracy.

Observations have been begun of various southern Me variables and stars of type R and N, partly with a view to determining radial velocities.

Spectra of the brightest members of the globular cluster 47 Tucanae are being obtained, chiefly at 48 A/mm. These include the three regular long-period variables whose radial velocities agree essentially with those of other members of the cluster.

The radial velocities of various objects in the Large Magellanic Cloud are being determined. S Doradus has been established as a member of the Cloud through its radial velocity.

Ten equatorial or southern stars, recently recommended by the I.A.U. Sub-Commission on Standard Velocity Stars, are being tested at 22 A/mm.

(*b*) *Stellar spectroscopy.*—A paper on the spectrum of Eta Carinae from 3670 to 8860 A has been communicated to the Society. New identifications include lines due to [P II], [S III] and [Co II]. A spectrum of a portion of the halo around Eta Carinae shows marked P Cygni characteristics. The reported brightening of Eta Carinae probably refers mainly to the surrounding halo. The current spectrum of RR Telescopii bears a strong resemblance to that of Eta Carinae except that the state of ionization is higher in RR Tel, which appears to be approaching the nebular stage of a slow nova.

Spectra of six stars in the Large Magellanic Cloud with bright hydrogen lines (including S Doradus) have been obtained at 48 A/mm. Two of them show [Fe II] lines, and in particular MWC 97 (HD 32763) shows a strong resemblance to Eta Carinae. The current spectral type of S Doradus appears to be A rather

than B in that Fe II appears without He. A special study has been begun of the luminous stars and nebular wisps involved in 30 Doradus.

A spectrum of the faint companion to π Gruis has been obtained which should provide a good estimate of the absolute magnitude of this typical S star. Spectra of some moderately close companions to Me variables are also being obtained.

The star HD 168476 has been found to have a spectrum closely similar to Popper's hydrogen-poor star HD 124448 (which has also been studied). HD 168476, which is brighter by $\frac{1}{2}$ mag., can be observed at 30 A/mm. Its remarkably high velocity of -160 km/sec cannot be attributed to galactic rotation.

Spectra of AL Velorum have been obtained during eclipse and during emergence from eclipse.

Spectra have been obtained of the following novae: Sagittarii 1952 I, Pictoris 1925, Puppis 1942.

(*c*) *Direct photography*.—Favourable weather in 1952 September to November yielded important new material on clusters lying in or near the Magellanic Clouds. 20 variables have been found in NGC 1466, and a few in or near NGC 1978, with characteristics which mark them as of short period ($P<1$ day). Comparisons with the equatorial Selected Area 94 establish that the median magnitudes of these variables are at least 0·8 mag. fainter than would be expected for the accepted distances of the Clouds. Definitive periods have been found for one long-period variable (141 days) and three short-period variables in NGC 121. An improved modulus for the Clouds must await revised magnitudes in S.A. 94 down to 20 mag.

More plates have been obtained of two regions of the Sagittarius Cloud for the study of variable stars. This material will probably be reduced at the Leiden Observatory.

Direct photographs in two colours of various extragalactic nebulae have been obtained by the Cape observers.

Five photographs of the field of the interesting planet Icarus were obtained in June and July. Positions of images measured at the Cape Observatory agree closely with an ephemeris by Dr S. Herrick.

(*d*) *Photoelectric photometry*.—The Cassegrain photometer was used, chiefly by Cape observers, during June to August, for photometry of stars down to the 12th magnitude, but the performance of the instrument is in many ways unsatisfactory. Laboratory tests upon it have been continued and it is hoped to make fuller use of it during 1953.

A sensitive E.M.I. cell was used by Dr D. S. Evans of the Cape Observatory in cooperation with the S.A. Council for Scientific and Industrial Research for a successful observation of the occultation (reappearance) of α Scorpii on 1952 April 13.

Dr Th. Walraven, of Leiden Observatory, installed a photometer at the Newtonian focus and used it for the observation of some cluster-type variables in two colours.

During a season somewhat above the average in quality the telescope was used on 299 nights. This is the first year throughout which the number of observers available has made it practicable to use clear skies to the full.

Visitors and staff.—The cooperation scheme with the Cape Observatory according to which one-third of the observing time is allotted to Cape observers has continued to operate very satisfactorily. Visiting members of the Cape staff have been J. Churms (throughout the year), A. W. J. Cousins, Dr D. S. Evans,

J. v. B. Lourens, A. Menzies, A. Morrisby and Dr R. H. Stoy. D. W. N. Stibbs, Radcliffe Travelling Fellow, worked at the Observatory assisted by Mrs Stibbs until departure for Oxford in September. Dr Th. Walraven and G. Westerhout of the Leiden Observatory also worked at the Observatory on various occasions during the year.

Other visitors to the Observatory during the year have included Sir Lawrence Bragg, Dr H. E. Butler, Dr H. Knox Shaw, Professor G. Lemaître, Professor J. H. Oort, Dr J. Ramberg, Dr W. van den Bos and other astronomers from the Union Observatory, Johannesburg.

During the year the Observatory lost the valuable services of Mrs M. G. Shuttleworth, part-time Secretary-Librarian, on her departure for U.S.A. Mrs M. Clayton has been appointed in her place.

Nizamiah Observatory, Hyderabad

(*Director, Dr Akbar Ali*)

Astrographic equatorial.—The 8-inch photovisual object glass of the Astrographic Equatorial which was sent to Messrs Cox, Hargreaves and Thomson Ltd., England for re-figuring and polishing has not, as yet, arrived here. Our Astrographic work has suffered a great deal on this account.

A few plates were taken, mostly in the ecliptic regions, with the Astro-Camera attached to the Astrographic Equatorial for cometary and minor planet work.

The results of the survey of photographic double stars in the zones $+36°$ to $+39°$ have been coordinated for publication in one volume. The survey and reduction of photographic doubles in the southern zones $-17°$ to $-23°$ have been taken up.

The studies undertaken in connection with the Recommendation 3 of the Carte-du-Ciel Commission of the I.A.U. (1948) are nearing completion and the results will be published shortly.

Grubb equatorial.—Micrometrical observations of the positions of the comet Wilson–Harrington (1951 i) and the minor planets Vesta and Pallas were made. The resulting positions were communicated to the I.A.U. Bureau at Copenhagen and to the Minor Planet Centre at Cincinnati.

20 occultations of stars by the Moon were observed during the year. Their reductions have been completed and the results will be communicated as usual to the Society.

Spectrohelioscope.—The Sun was observed on 152 days during the year with this instrument for one hour on the average per day. 10 flares were observed; 6 were of intensity 1 and the rest were of intensity 2. Their data have been sent for incorporation in the *Quarterly Bulletin of Solar Activity* (Zürich). Dark filaments were also observed with 18 shifts towards violet, 7 towards red, and 2 towards both.

Publications.—The following papers were sent for publication:

(1) "Stars with large proper motions in the Hyd. Astrographic Zones $+36°$ to $+39°$. Final list" (*Journal des Observateurs*, **35,** No. 10).

(2) "Occultations of stars by the Moon observed at the Nizamiah Observatory during the year 1951" (*M.N.*, **112,** 470).

(3) "Note on the double star BDS 9699" (*A.J.*, **57,** No. 5).

(4) "Observations of comet 1951 i and the minor planet Vesta made with the 15-inch Grubb refractor of Nizamiah Observatory, Hyderabad" (*The Hyderabad Academy Studies*, No. 13).

(5) "Atmosphere of the Sun" (*The Hyderabad Academy Studies*, No. 13).

Miscellaneous.—Lectures in Practical Astronomy were given to the graduate classes of the Osmania University.

The seismological work of the Observatory continued as usual.

Solar Physics Observatory, Kodaikanal

(*Director, Dr A. K. Das*)

General.—The Director attended the 8th General Assembly of the International Astronomical Union held at Rome in September and participated in the meetings and deliberations of the Assembly. Later he visited a number of astrophysical institutions in Europe and the United Kingdom in order to see the latest developments in astrophysics, particularly on the instrumental side.

International cooperation.—Exchange of spectroheliograms with foreign observatories was continued as before. 74 H-alpha flocculus and 69 calcium disk spectroheliograms taken at Kodaikanal during the years 1945, 1946 and 1947 were sent to Dr L. d'Azambuja, Director, Meudon Observatory, France, on request. 650 photographs of *K*-prominences at the limb pertaining to the years 1943–50 obtained from Mt. Wilson Observatory were sent to the Director, Arcetri Observatory, Florence, Italy. 40 H-alpha and 53 K_3 disk spectroheliograms relating to the period 1951 July to 1952 June were received from the Meudon Observatory, France. Periodical solar flare statements were sent as usual to Dr L. d'Azambuja of Meudon Observatory and Mr H. W. Newton of the Royal Greenwich Observatory.

The practice of broadcasting daily URSIGRAMMES relating to solar activity and of issuing warnings for expected ionospheric and geomagnetic disturbances was continued as in the previous year. From 1952 June 1 broadcasting of URSIGRAMMES relating to geomagnetic activity (based on Kodaikanal observations) was begun; these URSIGRAMMES are broadcast daily along with solar URSIGRAMMES.

Weather conditions.—Weather conditions during the year were more favourable than in the previous year, both as regards the number of days of observation and the quality of definition. Photographic observations were possible on 306 days while visual observations could be made on 319 days as compared with 298 and 311 days respectively during 1951. The average definition of the Sun's image estimated on a scale in which 1 is the worst and 5 the best was 2·82 compared with 2·76 in 1951. There were 71 days on which the definition was 2 or less and 40 days on which it was 4 or more.

Routine observations.—Observations with the photoheliograph, prominence spectroscope, spectrohelioscope and the spectroheliographs were carried out as before. Photoheliograms were obtained on 306 days, H-alpha and calcium disk spectroheliograms on 301 and 282 days respectively and calcium prominence photographs on 269 days, as compared with 298, 292, 285 and 276 days respectively in the previous year. Visual observations and sketches of sunspots were made on 319 days as against 311 days in 1951. Observations with the spectrohelioscope were possible on 309 days during the year compared with 299 days in 1951.

Sunspot activity.—There was considerable decrease in sunspot activity during the year. The details are given below:—

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
No. of new spot-groups	North	12	1	2	6	1	6	5	7	3	3	3	4	53
	Eq.													
	South	5	5	7	3	4	7	4	4	3	3	2	4	51
	Total	17	6	9	9	5	13	9	11	6	6	5	8	104
Mean daily number of spot-groups		2·8	1·6	1·5	1·6	1·5	2·7	2·3	3·2	1·9	1·3	1·3	2·2	1·99
Kodaikanal relative sunspot number		38·6	21·7	20·6	25·6	19·5	32·5	30·0	44·8	25·0	18·3	19·5	32·6	27·4

Compared with 1951, the decline in activity was steep, the decrease being 51 per cent in the total number of new groups, 50 per cent in the mean daily number of spot-groups and 55 per cent in the relative sunspot number. There were 38 spot-free days out of the total number of days of observation during the year as against none in 1951. The yearly mean latitude of all the spot-groups in the northern and the southern hemispheres separately was 9°·5 and 9°·7 respectively as against 11°·1 and 10°·1 for the previous year. There were 30 groups (15 in the north and 15 in the south) within the latitude range 0°–5° and three groups (two in the north and one in the south) whose mean latitude was more than 20°.

The largest spot-group of the year traversed the disk between the 16th and the 27th November. Its total area, corrected for foreshortening, was 1 100 millionths of the Sun's visible hemisphere as measured on the photoheliogram of November 21, the day of its central meridian passage.

Eclipse expedition.—An Indian eclipse expedition consisting of four members led by Dr A. K. Das went to Iraq to observe the total solar eclipse of February 25 and set up camp at Artawi (latitude 30° 33′ 28″, longitude 47° 05′ 52″) in the desert west of Basrah. Unfortunately the observational programme was frustrated by bad weather at the time of the eclipse.

"Bhavnagar" Telescope (20-inch Grubb reflector).—Preliminary adjustments of the "Bhavnagar" telescope were carried out during the year in order to put the telescope into commission.

Geomagnetic observations.—As in previous years, continuous photographic records of horizontal, vertical and declination elements of the Earth's magnetic field were made with Watson and LaCour magnetographs. A photoelectric recording *H*-magnetograph by Messrs Askania Werke, Berlin, was under installation.

Absolute measurements of *H* and *D* were made once a week with Kew magnetometer No. 3 and observations of inclination with an Earth Inductor on five days in the week.

During the year 25 magnetic storms of range $>150\gamma$ were recorded at Kodaikanal as compared with 24 in 1951. Of these, 6 were of the sudden commencement type. No storms were recorded with ranges in *H* exceeding 400γ.

Ionospheric observations.—Regular ionospheric observations were begun at Kodaikanal in 1952 January using a type C-3 Ionosphere Recorder developed by the Bureau of Standards, Washington, the observations being restricted to daylight hours for the time being.

Radio astronomy.—Continuous recording of solar noise flux was commenced using a 100 Mc/s radio-telescope.

Cosmic ray observations.—Continuous photographic recording of cosmic ray intensity was made throughout the year using a Kolhörster apparatus.

Seismology.—The Milne–Shaw seismograph (E–W component) recorded 213 earthquakes during the year. Of these 4 were severe and 11 moderate.

Meteorology.—Meteorological observations with all the visual and self-recording instruments were carried out as usual.

Library.—81 books and 1 143 periodicals were added to the library during the year. The library now has some 1 000 books and 10 000 periodicals relating to astronomy, astrophysics, physics, mathematics and allied subjects.

Workshop.—The machine shop of the Observatory was equipped with a milling machine, a shaping machine, a hack sawing machine, a slitting machine and a new lathe.

Research work and publications.—Under the Research Training Scheme sponsored by the Ministry of Education (Government of India), two junior scholars and one senior scholar were working in this Observatory during the year.

The following are the more important problems in solar physics which were under investigation during the year:

(*a*) Experimental study of centre-to-limb variation in the intensity of continuous spectrum over the solar disk throughout the photographic region of the spectrum;
(*b*) Study of the Balmer discontinuity in the ultra-violet region of the solar spectrum;
(*c*) Determination of the temperature of the Sun at the pole and the equator;
(*d*) Study of radiation flux across sunspots; and
(*e*) Study of solar noise at 100 Mc/s with a specially constructed receiver and recorder.

In geophysics, certain aspects of the variations in the Earth's magnetic field as revealed by the Kodaikanal magnetograms, such as the study of the diurnal variation of the horizontal force at Kodaikanal by harmonic analysis, sudden commencements in geomagnetic field variations at Kodaikanal, lunar magnetic and ionospheric variations at Kodaikanal, etc., were under investigation. Analysis of the cosmic ray records to study the periodic and non-periodic variations in cosmic ray intensity was in progress. Certain interesting features brought out by ionospheric observations such as the disappearance of ionospheric echoes at Kodaikanal in the pre-dawn period and their reappearance from greater virtual heights at about ground sunrise, etc. were studied. The study of fbEs and fE_{min} and their relationship with solar and geomagnetic phenomena was taken up.

The following notes and papers were published or sent for publication during the year:

(1) "Prominence Activity and the Sunspot Cycle", *Nature.*
(2) "Distribution of Radiation flux across Sunspots", *Zs. f. Ap.*
(3) A short article on "Kodaikanal Observatory", *Nature.*
(4) A note on "The Indian Eclipse Expedition to Iraq", *Indian J. of Met. and Geophysics.*
(5) A short note on the meeting of the 8th General Assembly of the International Astronomical Union held at Rome in 1952 September, *Indian J. of Met. and Geophysics.*

(6) "A New Early Morning Ionospheric Phenomenon", *Nature.*

(7) "Solar Noise Burst of 1952 April 11 and associated ionospheric and geomagnetic disturbances", *Indian J. of Met. and Geophysics.*

(8) "Spectrophotometric Study of Sunspots", *Indian Acad. of Sci.*

(9) *Kodaikanal Observatory Bulletin* for the 1st half of 1951, giving summary of the results of prominence and magnetic observations.

(10) Synopsis of solar and geomagnetic observations made at Kodaikanal during the 4th quarter of 1951 and 1st, 2nd and 3rd quarters of 1952, and synopsis of ionospheric observations made at Kodaikanal during the 3rd quarter of 1952, *Indian J. of Met. and Geophysics.*

Commonwealth Observatory, Mt. Stromlo

(*Director, Professor R. v. d. R. Woolley*)

The year 1952 was an eventful one in the history of the Observatory. On February 5 the whole mountain was overwhelmed by a bush fire, which was driven by a strong north-westerly wind over grasslands and scrub on the windward side of the Observatory, and which ultimately burnt the pine forest on Mt. Stromlo. Although the forest was mainly to leeward of the Observatory, the burning forest cut off all assistance from outside and burnt down the electric power lines. This was disastrous, as the water supply at the Observatory though copious has very little pressure, and the fire hoses rely on electrically operated pumps. The workshop was completely gutted by the fire, but no telescope dome, dwelling house or office building was lost. This relatively fortunate result was due to the resolution and skill with which the Observatory staff fought the fire.

The loss of the workshop meant a serious interruption in the Observatory's programme, but by the end of the year all the machine tools lost in the fire had been replaced (by purchase or in two cases reconditioning) and set to work in temporary accommodation. The opportunity was taken to rationalize the range of machine tools, and a new shop building has been commenced which has a far better layout than the one lost in the fire. It is expected that this will be completed during 1953.

Although the Observatory suffered a setback through fire, it progressed considerably with its general building programme. Indeed there was more visible progress in the last six months of 1952 than in the previous six years. The road along the north-western side of the Observatory is now complete, and along it stand the completed foundations of the Yale–Columbia 26-inch refractor and the 74-inch Grubb, Parsons reflector, and the building for the 50-inch telescope (the former Melbourne 48-inch). This building is now complete with dome, and the work on the telescope itself, which was held up for lack of cover against the weather, can proceed. During 1952 nine new dwelling houses were completed and handed over to the Observatory.

The Observatory acquired a 20-inch reflecting telescope, by Grubb, by purchase from the estate of the late J. H. Catts. This instrument was erected in August, and the mirror has been aluminized on Mt. Stromlo. The telescope is used for photoelectric observations.

During the year the 3-prism spectrograph was completed in the workshop, in spite of the disorganization caused by the fire.

Dr W. Buscome joined the staff on 1952 October 1; Dr Olin J. Eggen, of the Lick Observatory, who had been working on Mt. Stromlo for a year, left for America in March, and in July Professor Schilt of Columbia arrived, to spend approximately a year in Australia making arrangements for the Yale–Columbia station and carrying out photoelectric observations of colours of southern stars. He was joined in September by Mr C. Jackson who will remain on Mt. Stromlo permanently with the Yale–Columbia station.

Routine observations for determination of time were continued, but routine solar observations have been largely abandoned. Details of the time observations, and of the photoelectric and photographic observations of stellar magnitude carried out during the year by members of the staff, are given in the *Annual Report of the Commonwealth Astronomer*.

Riverview College Observatory, Sydney, N.S.W.

(*Director, T. N. Burke-Gaffney, S.J.*)

During 1952 the number of plates taken in the Variable Star programme (404), while less than that of 1951, was still above the average for post-war years. A number of occultations were also observed, but poor seeing conditions in the early part of the year kept the number low.

About the middle of the year, Rev. D. J. K. O'Connell, S.J., Director since 1938, was appointed Director of the Vatican Observatory, and he left Australia at the end of July. He has been succeeded as Director at Riverview by Rev. T. N. Burke-Gaffney, S.J. There has been no change in the work, or in the programme, hitherto observed, but the plans to install photoelectric equipment have been temporarily held up.

Additional staff accommodation was erected in the course of the year.

Sydney Observatory

(*Director, Mr Harley Wood, Government Astronomer*)

The work on the *Astrographic Catalogue* has been continued, Volume 30 of the Sydney section having been printed and distributed. Volume 34 is at present in the hands of the printer. Work on the Melbourne volumes has been undertaken at the request of the International Astronomical Union; Volume 4 is now ready to be printed and Volume 5 is in an advanced stage.

The programme of observations of occultations predicted in the *Nautical Almanac* has been continued. The results for 1950 and 1951 have been published and those for 1952 are being reduced.

The new dome to house the astrographic telescope has been completed and the telescope has now been re-erected.

The civil and educational work of the Observatory has continued as in previous years. An orrery was designed and constructed in the workshop to show the relative motions of the Sun, Earth and Moon.

Radiophysics Laboratory, Sydney

(*Director, Dr E. G. Bowen*)

In this report only that part of the work of the Laboratory which is concerned with radio astronomy is described. This relates to solar and cosmic radio waves

and to the effects of the terrestrial atmosphere on them. It is carried out under the direction of Dr J. L. Pawsey.

1. *Solar radio waves*

(*a*) *Interferometer observations on a wave-length of* 21 *centimetres.*—The 32-element interferometer for use on a wave-length of 21 centimetres was completed in February and has been in regular operation since then. It consists of thirty-two 6-ft. diameter parabolic aerials equally spaced along a 700-ft. east–west line. In a manner analogous to a diffraction grating it produces a series of knife-edge beams each about 3 minutes of arc in width and separated from its neighbour by about $1\frac{1}{2}$ degrees. The Sun passes through each beam in turn and is scanned stripwise at each such passage. The resolution is sufficient to resolve the individual "bright" areas which tend to occur on the Sun in association with sunspots.

The results are being studied from the point of view of determining the nature of the emission from these disturbed areas and also that of the background radiation from the quiet Sun. Further similar equipment is being set up along a line at right angles to the present equipment. The two equipments operating in conjunction will give two-dimensional information about the distribution of brightness over the solar disk.

(*b*) *Observations of dynamic spectra and of apparent position of metre-wave-length bursts.*—Equipment which measures spectra over the range from 40 to 280 Mc/s in a fraction of a second is now in operation. This permits effectively continuous observations of the changes in spectra during the lifetime of a burst of solar radio waves. The equipment consists of three separate receiving systems which are each tuned in succession over a range of about 2:1. It is intended to operate this equipment simultaneously with a direction-finding and polarization interferometer working on a frequency of 100 Mc/s which has been in use for some years. An interesting early observation with the spectrometer, the first outburst recorded, showed that two frequency bands were simultaneously present which maintained a ratio of 2:1 while the disturbance drifted from the high to the low frequency end of the range.

(*c*) *Routine observations.*—Regular observations of intensity have been taken on frequencies of 62, 98, 600, 1 200, 3 000 and 9 400 Mc/s and the results submitted to the *Quarterly Bulletin of Solar Activity*. The radio frequency section of this Bulletin is now edited by Mr Smerd of this Laboratory.

A spectrohelioscope, lent to the Laboratory by the Commonwealth Observatory, has been set up to take optical observations.

2. *Cosmic radio waves*

(*a*) 1 420 *Mc/s atomic hydrogen emission.*—The results of the first survey of the sky in the 1 420 Mc/s atomic hydrogen radiation were published. Interest centred on the discovery that the line was double over a quadrant of the Milky Way, a result which can be most simply explained as an effect of galactic rotation in relation to two vast elongated masses of hydrogen which are big enough to delineate spiral arms of the galaxy.

Equipment to give more precise and detailed observations is under construction. A novel feature is that the receiver simultaneously feeds several, e.g. 30, separate narrow-band tuned circuits whose outputs are individually recorded.

(*b*) *Discrete sources of cosmic radio waves.*—A further survey of discrete sources is in progress using a cliff-interferometer. It has been shown that, in addition to those of small size, there are a number of relatively intense sources with an angular extent exceeding a degree. The nature of these maxima in emission is not yet clear.

Accurate measurements have been made of the position of a number of the more intense of the well-known sources and these have strengthened previous identifications with optical objects. New equipment utilizing a radio link to extend the baseline of a two-aerial interferometer to about 10 miles was used to measure the angular size of a number of the above sources. They have all proved to have diameters of the order of a minute of arc. These measurements, through their conformity with the size of the optical objects, further strengthened optical identifications in a number of cases. The measurements are continuing.

(*c*) *Surveys of the distribution of cosmic radio waves over the sky.*—Surveys have been made over a part of the sky on the exceptionally low frequencies of 9 and 18 Mc/s and the results are being reduced.

3. *Effects of the terrestrial ionosphere*

Radio waves from cosmic sources pass through the whole of the terrestrial atmosphere before reaching the observer. At the longer wave-lengths used in radio astronomy, above about a metre say, the effects of the ionosphere are more prominent than those of the lower atmosphere. At these wave-lengths the principal effects include the scintillation of "radio stars"; refraction, which is significant in relation to accurate position measurements; and absorption, which is appreciable only at the longer wave-lengths.

An extended series of observations of "radio stars" on metre wave-lengths at low angles of elevation obtained with cliff-interferometers is now available. These observations are known to show scintillation phenomena which differ in important respects from English observations. The observations are now being studied in relation to scintillation and mean refraction.

The series of observations of cosmic radio waves on the very low frequencies of 9 and 18 Mc/s show absorption effects. On the basis of observations of the same part of the sky taken at different times, at which ionospheric effects differ, it has been possible to assess the total attenuation suffered by the waves under different ionospheric conditions and the proportion caused by different layers, D and F particularly, of the ionosphere.

4. *Visitors*

The Laboratory welcomed an exceptional number of overseas visitors in 1952 owing to the holding of the U.R.S.I. (Union Radio Scientifique Internationale) Assembly in Sydney during August. In radio astronomy, representatives from practically all the important centres throughout the world were present. Among those who have made important contributions to radio astronomy were : Sir Edward Appleton, R. Hanbury Brown, J. A. Ratcliffe, F. G. Smith (England); D. W. R. McKinley (Canada); M. Laffineur, M. J. Steinberg (France); C. A. Muller, A. H. de Voogt (Holland); N. Herlofson (Sweden); C. R. Burrows, H. I. Ewen, J. P. Hagen, R. A. Helliwell, L. A. Manning (U.S.A.).

5. *Publications during* 1952 :

Bracewell, R. N. " Radio Stars or Radio Nebulae ? ", *The Observatory*, **72**, 27-29, 1952.

Christiansen, W. N. and Hindman, J. V. " A Preliminary Survey of 1420 Mc/s Line Emission from Galactic Hydrogen ", *Aust. J. Sci. Res.* A, **5**, 437-455, 1952.

Christiansen, W. N. and Hindman, J. V., " 21-Centimetre Line Radiation from Galactic Hydrogen ", *The Observatory*, **72,** 149-151, 1952.

Kerr, F. J., " On the Possibility of Obtaining Radar Echoes from the Sun and Planets ", *Proc. Inst. Radio Engrs.*, **40,** 660-666, 1952.

Mills, B. Y., " The Distribution of the Discrete Sources of Cosmic Radio Radiation ", *Aust. J. Sci. Res.* A, **5,** 266-287, 1952.

Mills, B. Y., " The Positions of Six Discrete Sources of Cosmic Radio Radiation ", *Aust. J. Sci. Res.* A, **5,** 456-463, 1952.

Mills, B. Y., " Measurements of the Angular Sizes of Some Discrete Sources of Cosmic Noise,", *Nature*, **170,** 1061-1063, 1952.

Payne-Scott, Ruby and Little, A. G., " The Position and Movement on the Solar Disk of Sources of Radiation at a Frequency of 97 Mc/s. Part 3—Outbursts ", *Aust. J. Sci. Res.* A, **5,** 32-46, 1952.

Piddington, J. H. and Minnett, H. C., " Radio-Frequency Radiation from the Constellation of Cygnus ", *Aust. J. Sci. Res.* A, **5,** 17-31, 1952.

Wild, J. P., " The Radio-Frequency Line Spectrum of Atomic Hydrogen and its Applications in Astronomy ", *Astrophys. J.*, **115,** 206-221, 1952.

Perth Observatory

(*Director, Mr H. S. Spigl*)

The activities of the small staff available have been largely occupied with duties associated with the Western Australian Time Service; the seismograph and distribution of its records; the tide tables; the provision of astronomical information for the Press, legal and general purposes; and educational activities. The appointment of a part-time evening assistant will permit a better arrangement of numbers of visitors and evenings, and an increase of evening visits to reduce advance bookings.

Occultations have been observed with the 10-inch astrograph guiding telescope whenever possible, and the results sent to H.M. Nautical Almanac Office. Observations of sunspots by projection have been made throughout the year; and astronomical tables of various phenomena were distributed for a number of localities throughout the State.

The 12½-inch reflector has been re-conditioned and it is hoped to use this instrument for the visitors, and also make it available for the W.A. Astronomical Society on certain evenings.

Geophysical Observatory, Christchurch

(*Director, Mr J. W. Beagley*)

The routine ionospheric, magnetic and cosmic radiation recording programmes of the Observatory have been maintained, although staffing shortages have prevented the rapid progress of research projects being undertaken.

Much time was spent converting our ionosonde aerial systems to the multi-wire delta type, and extensive damage to one ionosphere recorder by lightning introduced additional problems. Construction of a fixed-frequency ionosonde for obtaining data on changes in ion-gradient at the lower boundary of the E region was commenced. The Earth-current recording project mentioned in the report for 1951 was extended so that data from two lines at right angles could be obtained. This experiment had to be stopped for some months while the recorder was used on another project.

The North–South experiment with the Blackett Cosmic Ray Intensity Recorder was completed and preparations made for similar work to be done in the East–West direction.

An investigation to determine changes in heights and thicknesses, as well as ionic densities, of the ionospheric layers during geomagnetic disturbances was started.

Carter Observatory, Wellington, N.Z.
(*Director, Mr I. L. Thomsen*)

As in previous years, the Observatory was open regularly to the public on Friday evenings from February to December for lectures and telescope demonstrations. Attendances totalled 2 109. In addition many lectures were given to institutions, societies and clubs.

Sunspot observations were continued and reported to Zürich Observatory, as well as other institutions interested in the data. For various reasons spectrohelioscope observations were temporarily suspended for the latter half of the year.

Owing to staff difficulties, only routine auroral work was maintained. Decrease in auroral activity has prevented any photographic work of note being performed. An article for the book *Antarctica Today* was written.

Occultation observations made in New Zealand for the years 1951 and 1952 were partially reduced and forwarded to H.M. Nautical Amanac Office.

During the opposition of Mars, 63 drawings on 25 nights were made by Messrs K. D. Adams and P. A. Head, mostly with the 9-inch refractor. The observations are in process of reduction. Mr Read, who is an artist by profession, also made some excellent colour drawings well worthy of study.

From July to December, the Director was at Lick Observatory as Martin Kellogg Fellow, where some routine radial velocity work was done with the 36-inch refractor under Dr G. Herbig, and photoelectric work on the 12-inch refractor under Dr G. Kron. Visits were paid to the Berkeley Astronomical Department, Mount Wilson and Palomar Observatories, the United States Naval Observatory and Harvard College Observatory.

Information has been supplied to the press, radio, legal firms, architects and others whenever requested. The Observatory has remained the headquarters of the Royal Astronomical Society of New Zealand, and much work was performed on behalf of the Society.

Godlee Observatory, Manchester

(*J. C. Farrer, S. W. R. Mottram, Assoc. M.C.T. and G. C. Marlowe*)

Work at the Godlee Observatory has continued throughout 1952 on very similar lines to that of the previous years, but has suffered more than usual from cloudy skies, and the necessity of stopping the work for a considerable period, for the replacement of a portion of the metallic covering of the dome.

Except for this period, solar drawings were made at mid-day, when weather conditions allowed, and these were supplemented by drawings made by members of the Manchester Astronomical Society with their own instruments.

Drawings were also made of various lunar formations, and of Mars and Jupiter. The Observatory was open every Thursday evening for members of the M.A.S., and on other evenings parties from various educational and cultural organizations were shown over the Observatory, and when weather conditions were unfavourable for observation, lantern lectures were given. Some 400 people availed themselves of these opportunities.

There was also a considerable demand for astronomical lectures and this was met by Wardens of the Observatory.

Observatory of the Hampstead Scientific Society

(*Secretaries, Miss M. Davies-Scourfield and Mr H. Wildey*)

The Observatory has continued to be much used both by members of the Society and by the general public.

An attempt to take a ciné film of the lunar eclipse on August 5 was defeated by cloud but a few test runs taken later were very encouraging. A short-focus reflector was used for this purpose and was attached to the 6-inch refractor so that the latter could be used as a guider.

Dr J. L. Haughton's Observatory, Charmouth, Dorset

Eight lunar occultations were observed and, as usual, the Observatory was open to the public from time to time, the number of visitors this year being 68.

The writer made use of being on a metallurgical mission to the United States to visit the Hayden and Adler planetaria in New York and Chicago, and the Dearborn Observatory, Evanston, Ill. He was also in a conducted tour over part of the U.S. Naval Observatory, Washington, D.C.

A few lectures on astronomical subjects were given and the usual daily meteorological observations were carried out.

Mr M. B. B. Heath's Observatory, Kingsteignton, S. Devon

Daylight observations of Mercury were made on 35 days and of Venus on 41 days, drawings being made on 3 and 5 days respectively. Owing to Mr Heath's absence in Spain, Mars was not observed until past opposition, but between May 11 and August 6 it was observed on 32 nights and 15 drawings made. Jupiter was observed on 22 nights, special attention being given to satellite phenomena, and 5 drawings made. Saturn was observed on 51 nights in continuance of the programme of intensity estimates, latitude of belts and satellite magnitude determinations.

The conjunction of Neptune with BD -6° 3827 was well observed.

Mr F. M. Holborn's Observatory, Peaslake, Surrey

During 1952, 73 variable stars and novae were observed on 157 nights, the number of observations being 2 310, excluding those for the purpose of establishing comparison star sequences. The Sun was observed on 225 days for spot counts and naked-eye spots. Most of the records were contributed to the British Astronomical Association. Those of γ Cassiopeiae for 1952 and previous years were sent to the Norman Lockyer Observatory.

Mr Patrick Moore's Observatory, East Grinstead, Sussex

Systematic lunar observations have been continued throughout 1952, particular attention being paid to the north-eastern limb area. Regular observations of Venus, Mars, Jupiter and Saturn have also been made, and reported to the appropriate Directors of the B.A.A. The 12½-inch Wilkins reflector, replacing the old 8½-inch, has been permanently installed, and a wooden observatory building erected.

Dr W. H. Steavenson's Observatory, Cambridge

The 30-inch reflector was used chiefly for photometric observations of novae, Pluto and the outer satellites of Uranus.

Physical observations were made of comets Schaumasse, Wilson-Harrington, Mrkos and Peltier, and also of both comets Harrington.

Mr H. Wildey's Observatory, Hampstead

The 20½-inch reflector has been used on Mars, Jupiter and comet searches.

Ciné experiments have been made at the Cassegrain focus on the Moon and Saturn and it is hoped to repeat these in the coming year.

Mr H. P. Wilkins' Observatory, Bexleyheath, Kent

Lunar and planetary observations have been continued with the 15¼-inch reflector, particular attention having been given to the lunar libratory regions and Mars.

Progress has been made in the preparation of an accurate, large-scale chart of the lunar libratory regions, greatly facilitated by observations with the Meudon 33-inch and Cambridge 25-inch refractors, also Dr W. H. Steavenson's 30-inch reflector. I wish to acknowledge my obligation to M. d'Azambuja (Meudon), Professor Redman and Dr Steavenson (Cambridge) for having kindly placed these instruments at my disposal. Their use has resulted in the detection of a large amount of minute and delicate lunar detail, hitherto unrecorded, enabling the limb irregularities to be accurately plotted under varying conditions of libration.

Several members of the Lunar Section of the British Astronomical Association have visited the Observatory, including Dr J. Q. Gant, of Washington, D.C., U.S.A.

REPORTS ON THE PROGRESS OF ASTRONOMY

GENERAL MAGNETIC FIELDS IN THE SUN AND STARS

H. W. Babcock and T. G. Cowling

Since the early work of G. E. Hale (**1, 2**) a number of attempts have been made to detect and measure the general magnetic field of the Sun. Also, magnetic fields on a large scale have been observed in a variety of stars. The first part of this report (by H.W.B.) will give a brief survey of the observational work on such fields. Theories of the fields will be briefly discussed in the second part (by T.G.C.).

Part I : Observations

As long ago as 1889, Bigelow (**3**) inferred that the Sun must be a magnet because the form of the coronal streamers, especially near the poles, suggests the lines of force of a magnetized sphere. Recently, van de Hulst (**4**) has concluded that a polar field of only 0·1 gauss would be sufficient to orient the streamers. The systematic change in form of the streamers with progress of the solar cycle, first mentioned by Hansky (**5**) and studied by Ludendorff (**6**), has suggested that the Sun's field is far from constant. But such evidence is only qualitative. Direct measurements of solar and stellar magnetism have depended entirely upon the Zeeman effect. The fact that this selective splitting of spectral lines into polarized components results in a fundamental way from the action of the magnetic field on the emitting or absorbing atoms makes this in principle an unambiguous and reliable method. It is generally recognized, however, that solar magnetic measurements (apart from sunspots) are of surpassing difficulty owing to the weakness of the field. As a result, a great deal of effort has been directed toward the development and testing of reliable and sensitive techniques of observation. The data hitherto obtained on the general field have been fragmentary and indeed controversial; it is only within the past year that sufficiently powerful equipment has been brought to bear to permit daily mapping of the magnetic field over the surface of the Sun with a precision of the order of one gauss (**7**).

The situation with regard to stellar magnetic fields is quite different. The apparatus, in the form of the fast, stable coudé grating spectrograph of the 100-inch telescope, had already been developed and thoroughly tested on other problems in stellar spectroscopy (**8**). In 1946, it remained only to provide a polarizing analyser in front of the slit and to examine selected stars for the Zeeman effect (**9**). Because some stars have fields of several thousand gauss, no very serious difficulty is encountered in measuring the Zeeman effect in their spectra by conventional photographic methods. In consequence, magnetic data have been accumulated for a number of stars, and some of these results are now available for interpretation.

The Zeeman effect.—In this effect there is a splitting of each spectral line into a symmetrical pattern centred on the undisturbed position of the line. The simplest pattern is the "normal triplet", which, observed in a field that is

transverse to the line of sight, consists of one central component and two others, half as strong, equally displaced on either side by an amount

$$\Delta\lambda = \pm 4{\cdot}67 \times 10^{-5}\lambda^2 H,$$

where λ is measured in cm and H in gauss. The central or p component is plane-polarized in a direction parallel to the lines of force; the displaced, or s, components are plane-polarized at right angles to the field direction. If the obliquity, γ, between the magnetic field and the line of sight is decreased, the p component is suppressed, for its intensity varies as $\sin^2\gamma$, while the polarization of the s components passes through decreasing degrees of ellipticity, becoming circular for the longitudinal Zeeman effect when $\gamma = 0$; at the same time, these components grow stronger, for the total intensity is conserved. The sign of circular polarization is opposite for the two s components. When the magnetic vector points toward the observer, the s component of higher frequency is levogyrate. We have adopted the definition that such a magnetic vector is positive in sign. An analyser for circularly polarized light will reject one of the s components and transmit the other (the same one whether the line is in emission or absorption), leading to a displacement $\Delta\lambda$ in the observed position of the line. This will hold even though, as in the Sun, $\Delta\lambda$ is very much smaller than the half-width of the line. Thus one usually deals with a blend of overlapping components of the Zeeman pattern. Seares (**10**) has shown that the shift of the "centre of gravity" of the blend (for emission lines or weak absorption lines), when observed through a circular analyser, is simply proportional to $\cos\gamma$. In astrophysical work the longitudinal effect has been employed almost exclusively in preference to the transverse effect, for it is easier to measure a small displacement of a line than to measure a small change in the sharpness of its profile.

Normal Zeeman triplets are shown by relatively few lines. More common are the anomalous patterns with more than three components, which may be regarded as arising from further splitting of the original three into groups that retain the initial polarization. For any line the pattern may be found by first computing the two Landé g factors for the spectroscopic terms involved, according to the formula

$$g = 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}.$$

For each term, the magnetic quantum number m varies from $-J$ to $+J$, by integers. One writes for each term a set of allowable values of mg, and takes differences between the two sets to arrive at the positions of the various components in the pattern. Patterns for all common transitions have been tabulated by Kiess and Meggers (**11**). For lines having triplet patterns the two g values are equal, being unity for the normal triplet, but in occasional instances reaching 2·5 or 3. If the gs are unequal, the anomalous patterns arise. For triplets and the much more common blended anomalous patterns (where account must be taken of unequal intensity of components in a group) the effective displacement as seen through a circular analyser is known as the z value; this has been tabulated for about 1500 lines often encountered in stellar spectra (**12**).

For the Sun and stars it has generally been assumed that the external magnetic field is similar to that of a dipole located at the centre. The field intensity at the surface, represented by

$$H = \tfrac{1}{2}H_p\sqrt{1 + 3\sin^2\phi}, \qquad (\phi = \text{latitude})$$

is then twice as strong at the poles as at the magnetic equator, and opposite in direction. For a star observed "pole-on", the magnetic polarity prevailing at the pole is predominant, as will be seen presently. When the Sun is observed from a distant point in its equatorial plane, the lines of force are parallel to the line of sight on the central meridian at latitudes of $\pm 36°$, but due to the increase of intensity with latitude, the greatest observable longitudinal Zeeman effect is to be expected at latitudes of $\pm 45°$ (**10**).

In describing the magnetic polarity of astronomical bodies it is often unsatisfactory to use the terms north and south because of confusion with the ordinary directional connotation of these terms. We employ the definition that a magnetic vector directed toward the observer is positive; hence a distant observer above the north geographic pole would say that the Earth's polarity is negative. (This is consistent with the fact that the Earth's magnetic polarity is opposite to that which would be induced by its rotation if it had a net positive electrical charge.) The extension of this system of specifying magnetic polarity to the Sun and stars through the Zeeman effect is obvious, even though for most stars we cannot determine the direction of rotation.

Solar observations.—The various observers who have attacked the problem of the Sun's magnetic field have used apparatus that performed basically the same functions, yet which differed greatly in design and operation. One requires an image-forming telescope, a polarizing analyser that is either compound or reversible, a spectrograph capable of yielding an accurate profile of the chosen line or lines, and an arrangement for measuring the slight shift of the line between the positions that correspond to opposite states of polarization.

The analyser consists basically of a crystal retardation plate, usually of mica or quartz, followed by a plane-polarizer such as a Nicol prism. The plate is chosen to produce a retardation of $(2n+1)\lambda/4$ between its fast and slow axes, and these axes are placed in azimuths of $\pm 45°$ with respect to the following plane-polarizer. A shift in azimuth of the retardation plate or of an intervening half-wave plate converts the analyser from the right-handed to the left-handed type. Unpolarized light is transmitted with half-intensity. When such a device is placed in front of the slit of a powerful spectrograph and supplied with light from a sunspot, for example, the lines are observed to be shifted in position as the sign of the analyser is reversed, in proportion to their magnetic sensitivity, or z-value. The shift between the displaced components (Δs, in microns) is measured and the component of the field in the line of sight is computed from the relation

$$H = 1{\cdot}07 \times 10^{9}\lambda^{-2}F\Delta s\, z^{-1},$$

where F is the dispersion in angstroms per millimetre and λ is in angstroms.

It is the function of the spectrograph to provide sufficient dispersion and resolving power, with freedom from scattered light, for the accurate rendition of the line profile. Since the useful solar lines have half-widths of about 0·1 A, it is readily surmised that an instrument capable of resolving lines only about 0·01 A apart is desirable. In the green, the desired resolving power is then about $\lambda/0{\cdot}01 = 550\,000$. With a grating of inferior resolving power, the observed line profile is wider, its sloping wings are less steep, and even worse, the profile will usually be asymmetrical, for this is a common failing of gratings (and of prisms (**13**)). On the other hand, very little gain is to be expected, on solar lines, by increasing the resolving power much above 600 000. Solar lines themselves,

incidentally, are far too wide to provide convenient critical tests of high resolution and of focus; such tests are readily made by inserting in front of the illuminated slit a cold absorption tube containing iodine vapour at low pressure (**14**). The numerous closely spaced lines thus produced are only about one-tenth as wide as solar lines. All observers of the solar Zeeman effect, until very recently, have been handicapped by the lack of sufficiently powerful gratings; some have attempted to overcome this difficulty by crossing a grating with an interferometer in order to achieve the required resolving power. The interferometer, however, is extremely sensitive to extraneous effects and requires great care in application. In its most stable form (the Lummer plate) it is not readily adapted for use with a photoelectric detector.

Hale (**15**) in 1908 discovered the magnetic nature of sunspots and measured their magnetic fields, sometimes as strong as 3 or 4 kilogauss. He later established the laws governing the magnetic polarity of spots and the solar magnetic cycle of about 22 years (**16**). From a study of spot spectra, he was able to select most of the lines that are highly sensitive for work on the Sun's general magnetic field, even before their exact patterns were determined in the laboratory.

For the investigation of the Sun's magnetic field, Hale (**17**) built in 1910 a 150-foot tower telescope with an underground spectrograph of 75-foot focus. In this he used the best plane grating available, a 6-inch ruled by A. A. Michelson, which had a resolving power of about 200 000 in the third order. The need for higher resolution and less scattered light was fully realized, and it was no coincidence that about 1914 Hale initiated a project for the development of a large ruling engine and the production of better gratings—a project that required some 35 years for fruition (**18**).

For an analyser in front of the slit, Hale used a Nicol prism preceded by a compound quarter-wave plate made of mica strips, each 2 mm wide; their fast axes alternated in position between plus and minus 45° with respect to the axis of the Nicol. For the longitudinal Zeeman effect the strips then gave each line a jagged appearance, and points along the line corresponded to various heliographic latitudes on a section of the solar meridian. The dispersion was about 0·2 A/mm, and for a sensitive line the displacements to be measured for a field of ten gauss were only about 0·003 mm. Recording was photographic and exposure times were 20 to 30 minutes, sufficient, together with the effects of imperfect seeing and guiding, to eliminate completely any transient Doppler shifts arising in solar granules. Altogether some 288 plates were taken in the first series of 1912, and hundreds of others in the following 20 years. Hale's original papers must be read for an appreciation of the scale on which the work was organized, the thoroughness with which it was carried out, and the precautions that were taken against error. At the same time, it must be recognized that the line profiles were affected by inadequate resolving power, scattered light and ghosts. Some astigmatism was present, resulting in poor definition of the edges of the mica strips as photographed on the plate. All of these factors increased the difficulties of measurement.

The plates were measured, usually with a tipping-plate micrometer, in such a way that the measurer was ignorant of the conditions under which they had been taken. The plotting of results from many thousands of individual settings on some 26 lines gave satisfactory evidence of a field that varied with latitude, clearly showing the expected reversal of polarity in passing from one hemisphere to the

other. The amplitude of the displacements, averaged for many lines, leads to a field intensity H_p at the north pole of about -20 gauss. Eighteen other lines which showed the expected splitting in spot spectra failed to show displacements in the measurements for the general field, and for this no very convincing explanation could be adduced. The investigators were of the opinion that the field intensity diminished rapidly with height in the atmosphere, and that the lines yielding the larger values might be indicative of the "true" field in the lower levels. The oft-quoted result of $(-)$ 50 gauss was indicated by only one line. If measures of all lines had simply been averaged, the result for H_p would have been closer to -10 than -20 gauss.

About 1932, Hale (**19**) enlisted the aid of several new investigators for new observations and remeasurement of the original plates. There were difficulties in confirming the earlier results (**20**) until R. M. Langer (**21, 22**) developed a new impersonal measuring machine with which settings could be made rapidly and recorded automatically. Langer measured many of the first series of plates and also those of 1922–23, concentrating on the line $\lambda 5247{\cdot}576$ ($z = 2{\cdot}5$). Fifty plates were measured at each latitude, involving some 25 000 settings, and the original results were verified. The change in polarity in passing from the northern to the southern hemisphere was easily visible; an amplitude of about one micron was quoted. This yields $H_p = -4$ gauss.

In a paper of 1935 that seems to have received little attention, Hale (**23**) summed up the re-investigations as follows:

"A study of four years has at last yielded a sufficient number of independent confirmations to satisfy us of the validity of our former conclusions . . . . Taken altogether, the evidence is overwhelmingly in favour of the existence, polarity, and order of magnitude of the general magnetic field of the Sun as given in our original papers."

The first attempts at photoelectric measurement of the Sun's general magnetic field were made by Dunham, Strong, Stebbins and Whitford in collaboration with Hale (**24**) at his Solar Laboratory in Pasadena about 1933. The newly constructed telescopic and spectrographic equipment was equivalent to that of the 150-foot solar tower on Mount Wilson. A circular quarter-wave plate was used in four positions above a Nicol in front of the slit, and an exit slit was placed on one sloping wing of the line $\lambda 5247$; this was followed by a photocell and a direct-coupled amplifier. The shift of the line in response to a change in the azimuth of the quarter-wave plate should result in a corresponding change in the intensity of the light received by the photocell. The results were not conclusive, but this is hardly surprising in view of the difficulty, with a d.c. method, of distinguishing between a very small true signal and the inevitable false modulation of the light by imperfections in the quarter-wave plate, all in the presence of "noise" and seeing fluctuations. These first attempts at eliminating the human factor in the measurements were nevertheless significant.

In 1933 a series of visual measurements was undertaken with the Mount Wilson solar equipment by Nicholson, Ellerman and Hickox (**25**), working with the line $\lambda 6173{\cdot}348$ ($z = 2{\cdot}5$). The compound analyser was used in front of the slit, but photography was avoided by employing a tipping plate in the eyepiece at the focal plane of the spectrograph. Thirty settings constituted one set of observations. The mean result of 54 sets between 1933 September 10 and 1934 January 6 was

$+3{\cdot}6 \pm 1{\cdot}7$ gauss. Another series of 30 sets made between 1948 October 1 and 1949 April 1 by Nicholson and Hickox (**26**) gave $-2{\cdot}0 \pm 2{\cdot}8$ gauss. All settings were made at $+45°$ heliographic latitude.

In order to obtain higher resolving power, H. D. Babcock (**27**) began the application of the interferometer to the study of solar Zeeman effects in 1939. He used a Lummer plate of high quality; both sides of the interference pattern were projected onto the slit of a 21-foot concave grating spectrograph which gave an auxiliary dispersion of 2·5 A/mm. The rigid requirements for proper adjustment of such an interferometer had been given by him previously (**28**). The analyser was a quartz plate cut parallel to the optic axis and used in two positions in succession. Various plates gave retardations of $(n \pm \frac{1}{4})\lambda_1$ and $(n \pm \frac{3}{4})\lambda_2$ for chosen lines λ_1 and λ_2. Recording was photographic and measurements were differential. The resolving power of 350 000 was frequently checked on the solar spectrum with an iodine tube. Heat-absorbing glass and colour filters were used to isolate the desired spectral region. The Lummer plate was enclosed in a thermally insulated box, but no thermostat was used, as such a device cannot eliminate the heating effects of the incident solar light. Instead, the plate was kept under good thermal conditions, illuminated for an hour before observing, and then quickly used for exposure of only two or three minutes with no change of illumination. Observations were made at $\pm 45°$ on the solar meridian using various pairs of lines such as λλ6173, 6302 and λλ5250, 5329. The first series of plates was obtained in 1940, and a new series was made annually, with one exception, until 1950. Forty-two sets of plates were measured, of which 18 sets showed general agreement with Hale's results, with H_p ranging from -6 to -60 gauss. The remaining 24 sets showed either no field or small positive values (**29**).

H. von Klüber (**30**), working independently but with a method quite similar to that of H. D. Babcock, likewise applied a Lummer plate interferometer to the study of the Sun's general magnetic field. The analyser was designed to give a differential effect for the two lines λ5250·216 and λ5263·32. Exposure times were 15 to 20 minutes. He measured about 60 plates taken in August and September of 1949 at $\pm 45°$ solar latitude, concluding that any possible field was smaller than one or two gauss.

In 1945, G. Thiessen (**31, 32**) had begun the development of apparatus combining an interferometer and a photoelectric detector. This was gradually improved and the precision of the measurements correspondingly increased. As reported in 1952, the equipment was mounted on a 60-cm equatorial refractor. A small concave grating was used for preliminary dispersion, followed by a Fabry–Perot interferometer and slit so adjusted that a narrow strip of the spectrum, about 0·03 A wide on the steep wing of λ5247, was admitted to the photomultiplier. The anode of the multiplier was connected directly to a galvanometer having a resonant frequency of 0·7 cycles per second, and the quarter-wave plate in front of a plane-polarizer was rotated by a synchronous motor at such a speed that the Zeeman shift of the line would produce a signal of the same frequency. The equivalent time constant of the detector was 63 seconds. The rotation of the quarter-wave plate produced a troublesome false modulation of the whole spectrum quite apart from any Zeeman effect, and this had to be compensated as well as possible by the synchronous rotation of a phased sector disk in front of the telescope objective. Deflections were calibrated by synchronously varying the air pressure

around the interferometer plates and thus introducing another, but known and reversible, component into the photoelectric signal. Observations were made at $\pm 45^\circ$ on the Sun's meridian. In 1947 and 1948, Thiessen obtained nearly identical values for H_p of $+1{\cdot}5 \pm 3{\cdot}5$ (m.e.) gauss. His observations of 1949 gave $+1{\cdot}5 \pm 0{\cdot}75$ gauss and for 1951 he reported $+2{\cdot}4 \pm 0{\cdot}5$ gauss. (Thiessen published his results with a negative sign, which indicated antiparallelism with the field of the Earth.)

In a brief investigation carried out in 1951, K. O. Kiepenheuer (**33**) used a photoelectric detector and a.c. amplifier with the 75-foot grating spectrograph on Mount Wilson. The resolving power with a bright grating as used in the second order was only 140 000. A photomultiplier was placed behind a slit on one wing of the line $\lambda 5250{\cdot}216$ ($z = 3$). The analyser consisted of a quarter-wave plate, a half-wave plate rotating at 60 r.p.s., and a Nicol; this arrangement produced a signal frequency of 240 cycles per second. A peaked amplifier suppressed false signal components of other frequencies that arose in part from the rotating elements. Elliptical polarization from the coelostat and second flat mirrors introduced an objectionable general modulation at the signal frequency; this varied with the hour angle of the Sun, and had to be compensated by the frequent adjustment of a tilted plane-polarizing glass plate just below the quarter-wave plate. Following the amplifier was a phase-sensitive rectifier and a filter with a time constant of about ten seconds. Kiepenheuer is stated to have worked with both the longitudinal and transverse effects, but the details are not clear. He reported no indication of a general field (limit 0·6 gauss), but did report observing patches containing no sunspots but showing fields of a few gauss. These were probably distinct from the "invisible spots" mentioned by Hale (**23**).

The various investigators of the Sun's magnetic field have exhibited great ingenuity in devising sensitive methods of detecting an exceedingly small and elusive effect, yet all have been handicapped in a number of ways by definite instrumental inadequacies. Photographic and direct visual observation, at first the only possibilities, are arduous and time consuming because so many individual settings are required to reduce the statistical errors. It is a serious disadvantage when results are not known until weeks or months after the observations. The users of photoelectric detectors have encountered difficulties due to modulation of the light by rotating optical elements in the analyser and in most instances due also to elliptical polarization by the mirrors of the telescope.

In an effort to overcome some of these difficulties, H. D. Babcock and H. W. Babcock assembled new apparatus at the Hale Solar Laboratory in 1952 (**7**). This has four noteworthy features: (1) The new grating installed in the 75-foot spectrograph is far superior to those previously used. It is blazed in the fifth order green, where the dispersion is 11 mm per angstrom and the resolving power is 600 000. (2) The analyser in front of the slit consists only of an electro-optic crystal (**34**) of ammonium dihydrogen phosphate (ADP) followed by a Nicol. An alternating voltage applied to the ADP plate causes it to become birefringent; its retardation varies between plus and minus a quarter-wave at a frequency of 120 cycles per second. Since the analyser has no moving parts, it can hardly produce a false modulation. (3) At the focal plane of the spectrograph not one but two slits are used, on opposite sides of the line profile where this is the steepest. The transmitted beams enter two separate photomultipliers that are connected to a difference amplifier (Fig. 1); thus any common signal

such as might arise from a general intensity modulation is rejected, but an enhanced response is obtained from the Zeeman effect. A narrow-band amplifier and a synchronous rectifier are followed by smoothing circuits having a time constant of one second. (4) The indication of magnetic intensity and polarity is presented on the screen of a cathode-ray tube equipped with deflection circuits that provide for continuous mapping as the solar image is scanned by allowing it to drift repeatedly across the slit in equidistant parallel traces. A camera focused on the screen of the tube then records in less than an hour's exposure

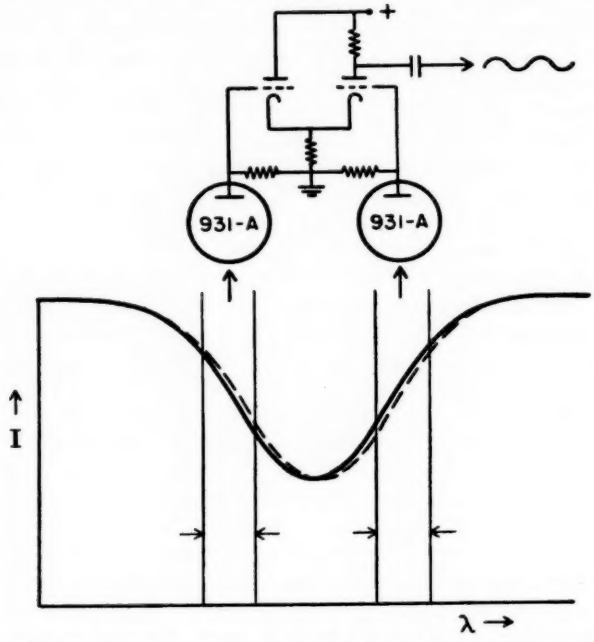


FIG. 1.—*Two slits on the wings of the line admit light to the two photomultipliers that are connected to a difference amplifier. In response to the alternating analyser, the line oscillates at a frequency of* 120 *cycles per second between the two positions into which it has been split by the magnetic field. The difference amplifier rejects any spurious general intensity modulation such as might arise from poor seeing.*

a magnetic record of the Sun such as that of Fig. 2. The r.m.s. noise which arises as shot effect in the photocurrent is equivalent to about one gauss when a time constant of one second is used. As the image drifts across the slit, the Doppler shift of the line arising from solar rotation is continuously compensated by the tilt of a plane-parallel glass plate in front of the exit slits. The solar mapping apparatus, which was put into use in the summer of 1952, has proved to be well adapted to routine observations, and it seems clear that we stand near the beginning of a period in which a considerable amount of new magnetic data can be accumulated. Only a brief preliminary report on the observations can be given here.

The magnetic pattern of the Sun is one of remarkable detail, usually comprising a number of rather localized multipolar fields as well as other magnetic areas, some quite extensive and some local, characterized by weaker fields ranging

down to the limit observable. In the vicinity of sunspots, outlying fields of the order of ten gauss are often observed, sometimes extending to distances of several minutes of arc on the disk. A considerable amount of detailed and persistent magnetic activity, sometimes as strong as thirty gauss, has often been revealed even when visible sunspots are few and small or absent entirely. Sometimes this occurs in regions that can be identified with bright clouds of Ca II which appear on spectroheliograms. The more prominent magnetic areas usually retain their identity from day to day, but with significant changes in extent and intensity. Further work will be required to establish the rapidity of fluctuations and the dimensions of the fine structure that seems to be present. Significant and

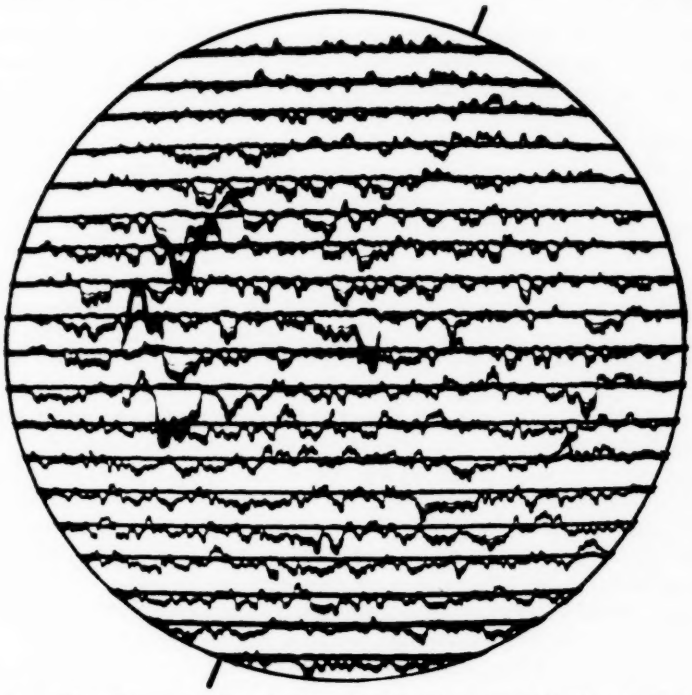


FIG. 2.—*Magnetic record of the disk of the Sun obtained on 1952 September 12 with the line* λ *5250·216* ($z=3$). *No sunspots were visible at the time. North is at the top, east at the right. The positions of the heliographic poles are indicated. For each magnetic trace there is a fiducial line. A deflection equal to the interval between lines is equivalent to about ten gauss. Upward deflections indicate that the magnetic vector is directed toward the Earth.*

persistent magnetic deflections have been observed at high solar latitudes, near $\pm 70°$, about as close to the heliographic poles as effective observations can be made. The predominant deflections are opposite near the north and south poles, and although they have been small, they tend to confirm the existence of a weak and distorted general dipolar field, with considerable fine structure. In the late summer and fall of 1952 the polarity has been positive—opposite to that of the Earth, opposite to that reported by Hale in 1913, and opposite to that of the leading sunspots in the northern hemisphere in the cycle now drawing to a close. These high-latitude fields have usually been studied with a longer instrumental

time constant than is used for scanning the disk. The component of the field in the line of sight seems to fluctuate from week to week, but has usually been of the order of one or two gauss. Since the lines of force are probably much inclined at these heliographic latitudes, the actual polar field strength may be considerably greater, perhaps two to four gauss. These polar fields are observed in latitudes from which, on coronal photographs, the short but prominent streamers known as "polar tufts" are seen to arise.

The apparent restriction of the dipolar part of the Sun's general field to quite high latitudes, and the irregular nature of the surface fields in latitudes below $\pm 60°$, suggest at once why the earlier observers, most of whom concentrated on measurements at $\pm 45°$, had so much difficulty in obtaining consistent results.

Clearly the current observations should be continued for an extended period, probably for a full 22-year solar cycle, in order to determine as much as possible about the local and general magnetic fields of the Sun and their variations.

Stellar magnetic fields.—The rapid axial rotation of many stars of early spectral type, with v_e of the order of 100 km/sec, has been known for many years from studies of Doppler line broadening (**35**). Comparison with the much slower rotation of the Sun ($v_e = 2$ km/sec) suggested that the rapidly rotating stars might have correspondingly stronger magnetic fields, with H_p possibly as great as a few thousand gauss (**36, 9**). If we are to observe the comparatively small line shifts due to Zeeman polarization, however, we must examine lines that are sharp and not greatly affected by rotational broadening. The rotational axes of the stars are probably directed at random; therefore, the small percentage of early-type stars with sharp spectral lines should include some that are in fact in rapid rotation, the axes being directed nearly toward the Earth.

The most reasonable initial assumption for stars, as for the Sun, is that the magnetic fields are dipolar. On this basis a formula has been derived relating the field intensity at the pole, H_p, to the line displacements found between the dextrogyrate and levogyrate spectra obtained with a polarizing analyser. Since we can examine only the spectrum of the integrated light of the star, it is necessary to integrate the effective magnetic field $H\cos\gamma$ over the surface, taking account of darkening at the limb. This was done for the general case by M. Schwarzschild (**37**), who showed that for a stellar dipole the effective field is

$$H_e = \frac{15+u}{15-5u} \cdot \tfrac{1}{4} H_p \cos i,$$

where u is the limb-darkening coefficient and i is the inclination of the magnetic axis to the line of sight. For a pole-on star with $u = 0{\cdot}45$ (type A) the Zeeman shifts are therefore 0·303 as great as for a purely longitudinal field of intensity H_p. If Δs is the measured Zeeman shift, in microns, between the images of the line in oppositely polarized spectra, and F is the dispersion in A/mm, then

$$H_p \cos i = 174 \left(\frac{4500}{\lambda}\right)^2 F\Delta s/z.$$

All the results for stars have been reported on the basis of this equation, usually with the assumption that $\cos i = 1$, even though in some instances the actual field can hardly bear a close resemblance to that of a dipole.

A multiple or double strip analyser of the type used by Hale for solar observations can transmit at most half of the light and would require trailing of the image if used on a star. A more efficient type for stellar work consists of a quarter-wave plate in contact with a calcite crystal several mm in thickness (**9**). Such an

analyser placed directly in front of the slit produces thereon two stellar images because of the double refraction of the calcite; the plane-polarization of the crystal, in orthogonal azimuths for the two images, provides that the circular analyser is of opposite sign for the two spectra that are photographed side by side. A decker in front of the quarter-wave plate limits the length of the slit and prevents contamination of the images if, in poor seeing, they become large. This analyser has the desirable features that the two oppositely polarized spectra are recorded simultaneously, and that none of the light is wasted. The comparison spectrum of the iron arc is introduced in the usual way at the beginning and end of the exposure, with the analyser removed.

In the analysis of polarized light with the coudé systems of the 100-inch and 200-inch telescopes, a minor complication is the phase shift introduced by the oblique reflections from the flat coudé mirrors. This effect is practically negligible for stars of southerly declination, but for those north of the equator the phase shift would be sufficient to reduce seriously the derived field intensity if it were not compensated. It has proved feasible to effect this compensation by means of a pair of crossed retardation plates mounted in front of the analyser; the azimuths of these plates are set as a function of declination.

The photographic method has proved quite efficient for observation of the stellar Zeeman effect, and it is unlikely that it will be supplanted by photoelectric methods in the near future. The narrow slit required, the faintness of the light, and the quantum nature of the photoelectric effect would limit this method to the brighter stars and considerable time would be required even for one observation of a single line. Photography, however, provides with one exposure a spectral range about 1000 A, often with scores of lines suitable for measurement. The same plates supply important collateral information on other characteristics, including velocities and line intensities, which are variable in many magnetic stars. Thus the amount of useful data gathered per hour of telescope time is much greater with photography. With the 200-inch telescope, for example, a double spectrum of a seventh magnitude A0 star at 4·5 A/mm can be obtained under average conditions in about two hours.

The probable error of measurement varies tremendously with the width and contrast of the stellar lines, the graininess of the emulsion, and the dispersion used. On the best plates of dispersion 2·9 A/mm the probable error of setting on a single line is 1 to 2 microns. This may be compared with a Zeeman displacement, Δs, of 35 microns for Fe λ4210 ($z=3$) measured in the spectrum of HD 125248 when H_p is about 7000 gauss. More commonly, the dispersion employed is 4·5 A/mm. From 20 to 50 stellar lines are usually measured on each plate. If the line widths are no greater than about 0·3 A, a field of 1500 gauss or more can usually be detected and the polarity assigned simply by examining the double spectrogram with a hand magnifier, before the plate is measured.

Approximately 1100 spectrograms have been made with the polarizing analyser, mostly with the 100-inch, a few with the 200-inch Hale reflector. About 600 of these plates are of the 35 stars in Table I, for which the presence of a magnetic field is regarded as established. In the spectra of some 20 additional stars, the Zeeman effect is strongly suspected, but more measurements are required. About 200 plates have been taken of other stars for which the effect is in doubt; for most of these any magnetic field is certainly not strong. About 65 stars, mostly tested on plates of 10 A/mm dispersion on the basis of "peculiar" spectral classification, have been rejected for measurement in the usual way

because of too few lines or too much rotational broadening. Stars with good lines that, upon measurement, have been found to have no field distinguishable from zero include α Equulei (F8), ε Pegasi (K0), γ Geminorum (A3), and Sirius (A0). The greater part of the measuring has been done by Miss Sylvia Burd and Mrs A. J. Deutsch.

TABLE I

Stars in which the Zeeman effect has been measured

Star	R.A. (1950) h m s	Dec. ° ′	m	Type	No. plates measured	H_p extremes		p.e.	Remarks
HD 2453	0 25 50	+32 09	6·7	A0p	1	−1520		±300	
HD 4174	0 41 53	+40 24	7·5	M2ep	4	+3500	−3900	±600	Hβ varies
HD 8441	1 21 23	+42 53	6·6	A0p	1	+1300	−....	±500	
HD 10783	1 43 04	+ 8 18	6·6	A3p	7	+5000	−2500		
HR 710	2 23 37	−15 34	5·8	A2p	11	−1070	−2970	±250	
HR 1105	3 37 48	+63 03	5·3	S	1	+1470		±210	
36 Eri	3 57 47	−24 09	4·7	A0p	1	+1360		±700	
μ Lep	5 10 41	−16 16	3·3	A0p	2	+ 620		±250	
WY Gem	6 08 54	+23 14	7	M3ep	1	+1800		±500	
HD 42616	6 10 10	+41 43	6·9	A0p	3	+2250	−2770	±600	
HD 49976	6 48 18	− 7 59	6·2	A0p	1	+3400		±800	
HD 60414, 5	7 31 30	−14 25	5·1	M3ep	1	−2200			
HD 71866	8 27 52	+40 24	6·7	A0p	1	−4000		±400	
3 Hya	8 33 02	− 7 48	5·6	A2p	7	+2440	−1600	±350	
49 Cnc	8 42 02	+10 16	5·6	A4p	5	+4000	− 600	±400	Sp. var.
45 Leo	10 25 01	+10 01	5·9	A0	3	+1000	− 250		Sp. var.
17 Com A	12 26 25	+26 11	5·4	A0p	3	−1600	−3800		Sp. var.
α^2 C Vn	12 53 42	+38 35	2·9	A0p	21	+5000	−4000		Sp. var.
78 Vir	13 31 35	+ 3 55	4·9	A2p	13	− 500	−3350	±200	Sp. var.
HD 125248	14 15 52	−18 29	5·7	A0p	29	+7000	−6000		Sp. var.
μ Lib A	14 46 34	−13 56	5·4	A4p	2	−1600	−3900	±400	
HD 133029	14 58 56	+47 28	6·2	A0p	45	+4300	+10500		~$1\frac{1}{2}^d$
β Cr B	15 25 46	+29 17	3·7	F0p	12	+2670	− 900	±150	
52 Her	16 47 46	+46 04	4·9	A2p	1	+2780		±300	
HD 153882	16 59 16	+15 01	6·2	A0p	20	+4500	−4000		$P = 6^d{\cdot}005$
HD 173650	18 43 28	+21 55	6·4	A0p	2	+1600	−1300	±350	
10 Aql	18 56 29	+13 50	5·9	A3p	2	+ 900	+ 460	±120	
21 Aql	19 11 11	+ 2 12	5·1	B8	4	+ 500	−1900	±500	
HD 188041	19 50 42	− 3 15	5·6	F0p	41	+1240	+4750	±150	$P = 226^d$
HD 192913	20 14 23	+27 37	6·7	A0p	1	−1730			
73 Dra	20 32 11	+74 47	5·2	A2p	5	−1200	−2300		Sp. var.
γ Equ	21 07 55	+ 9 56	4·8	F0p	9	+ 760	+2750	±110	
AG Peg	21 48 37	+12 23	7·6	B8p	5	−1400	−4000		
VV Cep	21 55 14	+63 23	5v	M2e	2	+2000	−1200	±300	
HD 224801	23 58 10	+44 58	6·2	A0p	1	+7500		±1400	

For no star listed in Table I is there good evidence that the magnetic field remains constant. In the table are given the maximum and minimum values derived for H_p, together with the number of plates completely measured for each star and the probable error of the determination from a single plate. Fourteen of the stars show reversal of polarity; eleven have positive H_p for all measurements and ten negative. For several stars, the results of detailed measurements are substantiated in some degree by eye estimates of additional plates.

For γ Equulei the observed polarity is positive, although H_p varies about a mean of +1700 gauss with an amplitude of roughly 1000 gauss. The direction of revolution of its eleventh magnitude companion, with a separation of 2″, is

clockwise, and the spin of the primary on its axis is probably in the same sense; therefore it is likewise probable that the magnetization is opposite to the rotation, as for the Earth (**38**). On plates of high dispersion, γ Equulei and 10 Aquilae have the sharpest lines of any stars in Table I, being nearly equalled in this respect by β Coronae Borealis and HD 188041. In the spectra of these four stars, the lines appear definitely sharper than those of any other "sharp-line" main-sequence stars not known to have a magnetic field; for example, the doublet Mg II λ 4481 is resolved into its two components 0·2 A apart.

Quite significant are the wide range of spectral types in the stars with magnetic fields, and the frequency with which such fields are associated with peculiar spectra. Of the stars in Table I, 27 were classified as peculiar members of types A or early F in the *Henry Draper Catalogue*, and of these six are listed as spectrum variables by Deutsch (**39**). It is in the outstanding spectrum variables that periodic magnetic variations of the largest amplitude have been found (**40, 41**). But the direct Zeeman effect has also been detected in the sharp bright metallic lines of AG Pegasi (Bep), which, as Merrill (**42**) showed, vary in a cycle of 800 days. Again, the absorption lines of four giant M-type stars show evidence of a magnetic field. These are HD 4174 (**43**), WY Gem, HD 60414, 5, and VV Cephei; all have peculiar spectra with emission features (**44**). In HD 4174, the magnetic field fluctuates in intervals of a few weeks, sometimes reversing polarity; the profile of Hβ is also observed to fluctuate between strong absorption and strong emission. R. E. Wilson (**45**) discovered that this high-velocity star has bright lines of H, [Ne III] and [O III]. One object of type S, HR 1105, has been found to have a magnetic field, probably variable.

All the evidence necessarily comes from fairly bright stars in which the magnetic field is sufficiently general—at least at certain times—so that the integrated light from all visible parts of the star has an outstanding magnetic polarity of one sign or the other. The measurements tell nothing directly about complex multipolar fields which in integrated light have no outstanding polarity. Taken together with the evidence from the Sun, this suggests that magnetic activity may be the rule in a large number of stellar atmospheres; that magnetic forces may be important in the ejection and support of the atoms that produce emission lines in some peculiar stars; and that certain abnormal abundance effects in the A and S stars may be associated in some way with the occurrence of a strong magnetic field.

To return to the peculiar A stars, it is noteworthy that apart from the spectrum variables there are a number of stars in which fluctuating magnetic fields, varying with more or less regularity, have been found. One of the best examples is HD 153882 (Aop), for which Miss Gjellestad (**46**) derived a period of 6·005 days; H_p varies periodically between +4 500 and −4 000 gauss. A non-harmonic variation in radial velocity was also found, but no changes in line intensity could be discerned. Another example is HD 188041 (Fop), in which the magnetic field, always of positive polarity, varies in a cycle of about 226 days (Fig. 3). At minimum, H_p is about +1 200 gauss; at maximum, which is variable in different cycles, it has reached about +4 800 gauss. The star having the strongest observed field is HD 133029 (Aop), not a spectrum variable, but a magnetic variable in which a maximum of +10 500 gauss has been measured (**47**). The minimum observed field is +4 300 gauss. There appears to be a secular variation and a short-period ($\sim 1\frac{1}{2}$ day) fluctuation with an amplitude of several hundred gauss.

In a magnetic field of several kilogauss, the Zeeman broadening of a line changes its absorption coefficient, and may increase the equivalent width appreciably (**48**); while this effect undoubtedly occurs, it is relatively a minor one, and in general might be revealed only by precise microphotometry.

Another line-intensity effect of greater moment though of more obscure interpretation is found in the spectrum variables of type A, where the effective

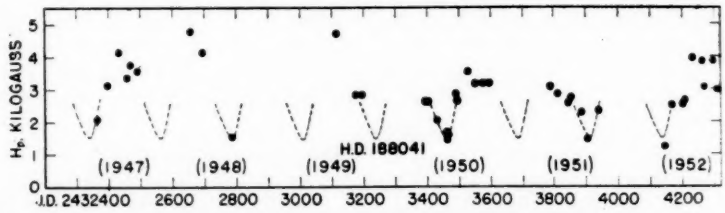


FIG. 3.—*Polar magnetic field intensity measured for HD* 188041 (Fop) *on* 41 *dates since* 1947. *The probable error of each determination is about* ±150 *gauss. Minima seem to recur regularly at intervals of about* 226 *days. The amplitudes of the various maxima are non-uniform.*

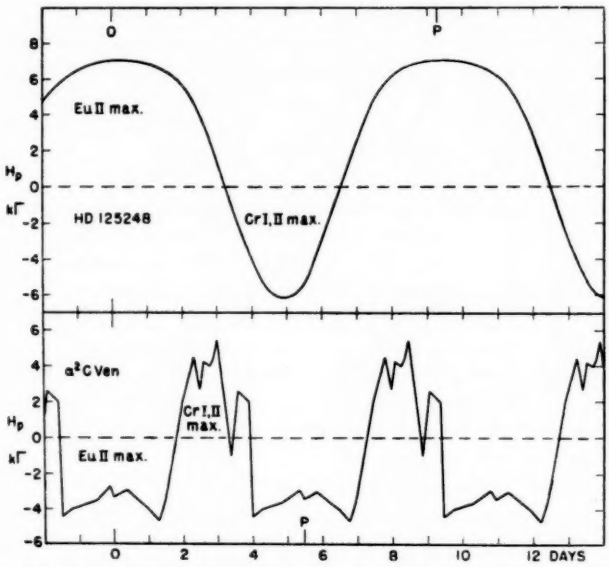


FIG. 4.—*Mean curves of magnetic variation for two outstanding variables. The field intensity at the pole, in kilogauss, is plotted against time in days. In HD* 125248 *the magnetic polarity is positive when the lines of Eu II are at maximum intensity, but the reverse is true for* α^2 *C Vn.*

abundance of a few elements appears to vary periodically, in step with a regularly varying magnetic field. The outstanding examples are HD 125248 (Aop) (**40**) and α^2 Canum Venaticorum (Aop) (**41**), with periods of 9·298 days and 5·46939 days, respectively (Fig. 4). In each, the polarity of the magnetic field is reversed periodically, with an amplitude of over six kilogauss in the former and four kilogauss in the latter. While the intensities of many of the spectral lines, such as those of Fe I and Fe II, are essentially invariant, the lines of two groups of

elements in each star, characterized by Eu II and by Cr I–Cr II, vary widely in intensity, the two groups changing in opposite phase. It has been impossible to explain satisfactorily the variations in line intensity on the basis of ionization (**49**). For example, Cr I and Cr II grow weak and strong together.

Other data bearing on the problem of the spectrum variables include radial velocities (different elements giving different velocity curves) (**50, 41**), periods (**39**), line profiles both in integrated and in polarized light (**40**), and light curves (**51**). In many respects the observations are as yet scanty and of low precision.

Part II: Theory

No really satisfactory theory of stellar magnetic fields has yet been given. In some ways this is not surprising; no really satisfactory theory of the Earth's field exists, and the properties of terrestrial material can be studied far more readily than those of material at stellar temperatures. Nevertheless, the present situation cannot but be regarded as a challenge to theoreticians.

Fundamental theories.—The first and most obvious suggestion is that a star's magnetism is due to its rotation. Schuster (**52**) supposed that any large rotating mass, such as the Earth or the Sun, must be a magnet; and Hale (**15**) was first led to investigate solar magnetism because he thought that a rotating ionized gas must generate magnetism through the motions of the charged particles. The difficulty is, however, to find a mechanism by which the rotation can produce an appreciable magnetic field.

Because of their lightness, electrons tend to rise above the heavy ions in a star, so as to produce a positive volume charge in the interior, and a negative surface charge; the rotation of these charges might be expected to give rise to the observed magnetic field. But Brunt (**53**) showed that in the Sun the field due to this effect is less than 10^{-13} gauss; the results for other stars are very similar. Again, in ferromagnetic materials a gyromagnetic effect is observed (**54**); that is, when under laboratory conditions an iron body is rotated rapidly, it acquires magnetic moment and exerts an observable magnetic force. But there is no evidence that ferromagnetic properties can persist at stellar temperatures; moreover, the magnetic field, being proportional to the angular velocity, would be very tiny even if the star were ferromagnetic.

It is indeed difficult to see how mere rotation can produce a magnetic field unless the laws of physics are fundamentally modified. Modifications of the laws of physics have been proposed by a number of authors; they provide the so-called *fundamental* theories of stellar magnetism. The most important of these is one originated by H. A. Wilson (**55**), and later revived by Blackett (**56**) and, in a less developed form, by H. W. Babcock (**57**); this asserts that a large rotating mass possesses a magnetic moment $\beta G^{1/2}c^{-1}$ times its angular momentum, where G is the gravitational constant, c the velocity of light, and β a pure number of order unity. A full account of this and other fundamental theories was given in Blackett's paper.

Wilson's theory was based on the hypothesis that a moving mass m behaved, so far as magnetic effects are concerned, like an electric charge of magnitude (about) $G^{1/2}m/c$, though the electrostatic effect to be expected from such a charge does not appear. When it was revived by Blackett, the observational data appeared to suggest that the magnetic moments of the Earth, the Sun and the star 78 Virginis were in fact proportional to their angular momenta, with about the

right constant of proportionality. Later results gave no similar support to the theory. Terrestrial observations in mines, after first appearing to support the theory, finally indicated that the angular momentum of surface rocks was responsible for no appreciable contribution to the magnetic moment (**58**). Large masses in the laboratory were equally shown to produce no magnetic effects due to their rotation with the Earth (**59**). Moreover, the magnetic moments of Earth, Sun and stars appear to be highly variable, and the magnetic axis of the Earth is inclined to the rotational axis at a considerable angle; indeed, some evidence suggests that the magnetic polarity of the Earth may have been completely reversed more than once in the past.

The theory also meets with serious theoretical difficulties. It demands the non-appearance of the electric effect of the equivalent charge $G^{1/2}m/c$, while insisting on its magnetic effects. Since magnetic and electric effects are, according to the theory of relativity, only different facets of the same entity, it is difficult to find a way of getting the one without the other, and no satisfactory way of doing so has been devised. Milne (**60**) indeed attempted to deduce magnetic effects from rotation by the equations of kinematical relativity, but his discussion was obscure and open to question, and in any case it gave a field far less than observed stellar fields. A derivation by Gião (**61**) was even more obscure and difficult.

In any case a fundamental theory should be invoked only if other evidence suggests that existing physical laws are inadequate, or all other possibilities have proved fruitless. As stated earlier, other theories have not yet provided an adequate explanation of the fields; nevertheless, he would be bold who suggested that all the possibilities had been exhausted. Fundamental theories are therefore best put on one side until other theories have been studied more fully.

Fossil magnetism.—Although permanent magnetism of the ferromagnetic kind is impossible at stellar temperatures, stellar magnetic fields have a high degree of permanence. The fields must be accompanied by electric currents in the body of the star. Now when a current is left to decay freely in a circuit of resistance R and self-induction L, it decays exponentially, with time of decay L/R. This time is small in laboratory circuits. However, stellar currents flow in circuits of enormous cross-section; this results in a large L and a small R and so in a very great time of decay. Thus the currents, and the field which they accompany, are relatively permanent.

In the free decay of a magnetic field in a conducting fluid at rest, the field strength $\mathbf{H}$ satisfies the equation

$$4\pi\sigma\frac{\partial \mathbf{H}}{\partial t} = \nabla^2\mathbf{H}, \tag{1}$$

where σ is the conductivity (in e.m.u.); the magnetic permeability is taken as unity. In this, $\partial\mathbf{H}/\partial t$ is comparable with $\mathbf{H}/\tau$, where τ is the time of decay; $\nabla^2\mathbf{H}$ is comparable with $\mathbf{H}/l^2$, where l is a scale-length characteristic of the field. Thus, so far as orders of magnitude are concerned,

$$\tau \sim 4\pi\bar{\sigma}l^2, \tag{2}$$

where $\bar{\sigma}$ is a mean value of the conductivity. This indicates how the time of decay increases with increasing size of the conducting mass. For example, in the Sun σ is greater than 10^{-4} e.m.u. throughout a sphere whose radius is about half the solar radius. Taking $\bar{\sigma} = 10^{-4}$ e.m.u. and $l = 3{\cdot}5 \times 10^{10}$ cm, we get from (2)

$$\tau \sim 5 \times 10^{10} \text{ years.}$$

A more exact investigation gives a rather smaller time of decay (about 10^{10} years (**62**)) but one which is still decidedly greater than the normally accepted lifetime of the solar system. For early-type stars the times of decay are greater still, and may again be expected to be greater than the star's lifetime.

This introduces the possibility that the present magnetic fields of stars may be no more than "fossil" relics of fields which the stars possessed at their birth. Observations of the polarization of starlight (**63, 64**)—not Zeeman polarization, but an effect believed due to scattering by interstellar particles—suggest that, over wide ranges in the galactic plane, interstellar particles are oriented preferentially perpendicular to the galactic plane. One possible explanation of this is that the particles are orientated by a galactic magnetic field; such a magnetic field is also invoked in certain theories of cosmic rays. Assuming the existence of such a field, a simple argument suggests that, if a star is born as a result of the condensation of interstellar material, it initially possesses a large magnetic field, of which the present field is a relic.

In a moving conducting fluid whose velocity at any point is $\mathbf{v}$, equation (1) is replaced by

$$4\pi\sigma\left(\frac{\partial \mathbf{H}}{\partial t} - \operatorname{curl}(\mathbf{v}\times\mathbf{H})\right) = \nabla^2\mathbf{H}. \tag{3}$$

In interstellar material (and usually also in stars), because of the enormous scale-lengths characteristic of the field, the term $\nabla^2\mathbf{H}$ in this equation is small compared with that involving $\mathbf{v}\times\mathbf{H}$ if $\mathbf{v}$ is at all appreciable. Hence the equation approximates closely to

$$\frac{\partial \mathbf{H}}{\partial t} = \operatorname{curl}(\mathbf{v}\times\mathbf{H}), \tag{4}$$

which is the equation valid for perfectly conducting material. Thus, as in a perfectly conducting medium, the lines of force are "frozen" into the material; that is, the material can flow freely along the lines of force, but if it has any motion perpendicular to the lines of force, it carries them with it in its motion.

Suppose that a star is formed by condensation from interstellar material in a region where the magnetic field is sensibly uniform in direction. During the condensation the density increases by a factor of, say, 10^{24}; thus, assuming the same degree of contraction in all directions, the linear dimensions of the mass forming the star are reduced in the ratio $10^8:1$. The contraction squeezes the lines of force together, the total magnetic induction through the mass remaining constant; thus the magnetic field increases in the ratio $10^{16}:1$. Hence, if one were to begin with a field of order 10^{-5} gauss, such as is quoted by some theoretical workers to explain the polarization of starlight, the contraction would increase this to 10^{11} gauss. So high a figure is altogether impossible, since the mechanical effects of a field of 10^{11} gauss would be so strong as altogether to prevent gravitational forces from pushing the material together. If the initial field were as high as 10^{-5} gauss, most of the contraction would have to be supposed to take place along the lines of force: to get a stellar field of 10^5 gauss one need only assume a lateral contraction in the ratio $10^5:1$. But a similar field could also be obtained by assuming a uniform contraction, and an initial field of only 10^{-11} gauss.

The "fossil" theory of stellar magnetism has, however, certain difficulties. For example, the time of decay of the field was estimated assuming the material to be at rest. But we have seen that, if large-scale motions take place in a star, in addition to the decay there are much greater effects because convected material

tends to carry its magnetic field with it. Thus turbulent motion may split up the field into a number of lesser elements, which may be destroyed in detail in a much shorter time than was found above. This objection cannot, of course, be pressed too far. The increased rate of destruction of a magnetic field due to mass motions is equivalent to an increase in the electrical resistance (**65**) and so leads to a reduction in the steady magnetic field which can be maintained by a given applied e.m.f. If the mass motions increase the rate of destruction of a field too much, one reaches the reductio ad absurdum that virtually no agency whatsoever can maintain an observable magnetic field.

A second difficulty is that the magnitude, and even the existence, of galactic magnetic fields is not certainly known. While one possible explanation of the polarization of starlight by interstellar particles is in terms of magnetic fields (**66, 67**), others make no use of such fields (**68**). Theoretical arguments suggesting the existence of galactic fields of order 10^{-5} gauss have indeed been advanced (**69**); these are based on the assumption of a tiny initial "seed" field, much augmented as turbulent motion extends the lines of force and crowds them together laterally. But while it is certainly true that turbulent motion tends to augment any initial "seed" field, no obvious reason exists why the field should increase regularly. A more natural expectation is that turbulent motion should tend to twist the lines of force into a steadily more confused tangle. Large stellar magnetic fields can be produced only if the field in interstellar material before its contraction to form a star has an appreciable component which is reasonably uniform in direction, and there is no obvious reason why the mechanism described should produce such a component. Here again, however, the objection cannot be pressed too far, since a uniform interstellar field not much bigger than 10^{-11} gauss would probably be enough to produce the observed stellar fields.

The details of the formation of stars are largely matters for conjecture, and the objections against the "fossil" theory can be summarized by saying that it makes too many appeals to what is at best imperfectly known. But since it does provide a possible explanation of stellar fields, it cannot be discarded out of hand.

Pressure currents.—In certain circumstances electric currents can flow in an ionized gas, even though no electric forces act. It is convenient loosely to call these currents pressure currents, though they in fact arise from the interaction of pressure, temperature and other effects.

The fundamental fact in this connection is that electrons diffuse far more rapidly out of regions of high pressure than do the heavy ions. A pressure gradient in consequence produces the same electric current in a totally ionized gas as an electric field $\mathbf{E}'$, where

$$\mathbf{E}' = \frac{1}{n_e e} \operatorname{grad} p_e. \tag{5}$$

Here $-e$ is the electronic charge, and p_e and n_e are the partial pressure and number-density of electrons. In a spherically symmetric star the equivalent electric force $\mathbf{E}'$ has very little significance; it leads to a slight diffusion of electrons outward, but the charge distribution thus set up at once produces an electric force which exactly balances $\mathbf{E}'$ and stops any further flow of electric currents. Thus in the case of spherical symmetry the only effect of $\mathbf{E}'$ is to produce a very small volume-distribution of charge—precisely that whose rotation was shown by Brunt to be completely inadequate to explain the Sun's field. But in the absence of spherical symmetry (more precisely, when the surfaces of constant temperature

and electron-pressure do not coincide) $\mathbf{E}'$ cannot be wholly neutralized by an electrostatic field, and currents will flow.

Biermann (**70**) considered the currents arising when spherical symmetry is disturbed by non-uniform rotation. With uniform rotation, $\mathbf{E}'$ can still be neutralized by an electrostatic field; with non-uniform rotation a fraction of it in general remains unneutralized, the order of magnitude of the fraction being given by the ratio of centrifugal force to gravity. Assuming an angular velocity varying as an inverse power of the distance from the centre, Biermann was able to obtain fields up to about 1 000 gauss for a star like the Sun. For an early-type star, with greater rotational velocity, much greater fields can be obtained. These are the steady-state fields: since the time taken for the steady-state value to be attained (10^{10} years or more) may be greater than the star's lifetime, the actual field to be expected is smaller—say a few hundred gauss for the Sun, but 10 000 gauss for an early-type star rotating ten times as fast.

However, as Biermann recognized, this does not provide an immediate explanation of the observed stellar fields. The equivalent electric force $\mathbf{E}'$, and the currents which it drives, are in meridian planes through the axis of rotation. Thus the lines of force of the resulting magnetic field are circles with the axis of rotation as axis of symmetry. The field is wholly internal: because of symmetry of the current-system with respect to the equatorial plane, the fields on opposite sides of this plane are in opposite senses. An observable field can be produced only if the lines of force can be brought to the surface. This could not be effected at all if the lines of force were completely "frozen" into the material; but convection might lift lines of force nearly to the surface, and they might then slowly "leak" through the less conducting surface layers into outer space. The external field so produced would, however, be far smaller than the internal field. It would be an irregular field subject to a good deal of variation, and any dipole component which it might possess would have no obvious relation to the axis of rotation. Whether it could explain the observed fields is somewhat dubious.

Cowling and Biermann both sought to derive currents round the axis of rotation of a star from $\mathbf{E}'$ so as to get a dipole field with the rotational axis as axis. Cowling (**62**) supposed that, when thermal instability causes convection in a rotating star, the effect of Coriolis forces is largely cancelled by azimuthal pressure gradients. He thus obtained an azimuthal $\mathbf{E}'$, oppositely directed in rising and falling elements of gas; because of the factor $1/n_e$ in (5), however, the $\mathbf{E}'$ in the rising, warmer elements is slightly more important than that in falling, cooler elements. This means that there is a small resultant azimuthal current. However, since this depends on both the small Coriolis forces and the small temperature-excess for rising elements over falling, it leads to very small fields—less than 10^{-6} gauss for the Sun.

Biermann (**70**) imagined a rapidly rotating star to possess a comparably rapid internal circulation, in which (say) material rises near the axis of rotation, travels to the equator near the surface, and sinks near the equatorial plane. The circulation and turbulent viscosity between them produce a steady distribution of angular velocity through the star, each circulating element being continuously accelerated by turbulent viscosity to bring its angular velocity to the value appropriate to its position. Biermann supposed the pressure gradients required to produce the azimuthal acceleration to be those effective in $\mathbf{E}'$. He thus obtained azimuthal currents; assuming the velocities of circulation and rotation to be

similar in order of magnitude, the fields due to these azimuthal currents are comparable with those found earlier from non-uniform rotation. However, quite apart from the fact that the origin of such large circulations is unexplained, the accelerations due to turbulent viscosity do not lead to electric currents. Turbulent viscosity does not affect the motion through an azimuthal pressure gradient (as would be required if (5) is to be used) but because moving elements of matter transport their momentum with them to their new surroundings.

Hoyle (**71**) considered the possibility that the Sun might have been magnetized from outside. He supposed accretion of neutral hydrogen to have occurred at an enhanced rate at some earlier epoch; the hydrogen falling into the Sun was supposed not to share the Sun's rotation. The interaction of the neutral hydrogen with electrons in the outer atmosphere makes these lag behind the positive ions, and so leads to electric currents round the Sun's axis. The magnetic field thus generated then leaks slowly into the Sun's outer layers. Hoyle envisaged the period of rapid accretion to be, say, 5×10^5 years; during such a period the field would be able to invade only the outer "skin" of the Sun. When the enhanced accretion stops, the field disappears in a time comparable with the time of excitation by accretion.

The whole accretion question is highly controversial. However, the real weakness of Hoyle's argument is that it neglects the mechanical forces due to the growing magnetic field. A field of less than 1 gauss in the chromosphere is able, by making charged particles hook on to the lines of magnetic force, to destroy relative motions of ions and electrons. Moreover, a magnetic field H exerts stresses of magnitude $H^2/8\pi$ on the material carrying the currents; thus even a field of magnitude 1 gauss produces stresses comparable with the pressure in the chromosphere. The mechanical effects of magnetic fields are indeed so important that no theory is likely to work which ascribes the generation of stellar fields to atmospheric currents.

Dynamo theories.—A further class of theory explains the maintenance of the magnetic field by currents induced in the material as a result of its motion in the field. The mechanism here is similar to that in a self-exciting dynamo.

The modern discussion of dynamo theories was initiated by Larmor in 1919 (**72**) in a discussion of solar fields. He considered the Sun's field to be roughly symmetric with respect to the axis of rotation. He then pointed out that, if material near the centre flowed inward towards the axis of rotation across the lines of force, currents were induced which flow round the axis in the sense required to maintain the field. If near the poles material flowed outward, away from the axis of rotation, across the lines of force, the currents induced here opposed the maintenance; but the currents near the centre could be expected to be the more important, because of the high conductivity there. The velocity required to produce maintenance is estimated by a rough calculation as very small—for the Sun, less than 10^{-6} cm/sec.

However, Cowling (**73**) was able to show that dynamo maintenance is impossible if the field and the motion which is to maintain it are axially symmetric, the direction of each at any point lying in the plane through this point and the axis. He pointed out that the field vanishes on a circle round the axis, and that no induced current could therefore flow round this circle, whereas maintenance of the field near the circle demanded that a current should flow round it. Cowling's result is easily understood in terms of equation (3). This indicates that $\partial \mathbf{H}/\partial t$

is the sum of two parts, one due to the transport of the lines of force with the material (the curl $(\mathbf{v} \times \mathbf{H})$ term) and the other representing the slow leak of the lines of force through the material. If matter near the centre of the Sun flows inwards towards the axis, the motion tends to press the lines of force together and so to increase the field near the centre; if matter near the poles flows outward, away from the axis, the lines of force are separated and the field here tends to decrease. These are recognizably the results to which Larmor appealed. But since the motion is effectively only displacing the lines of force, it may modify the process of decay of the field due to the leak effect, but cannot wholly prevent it. Thus maintenance of a steady field is impossible.

Cowling's proof referred only to an axially symmetric field or one with similar properties. Elsasser (**74**) and Bullard (**75**) have more recently attempted to obtain dynamo maintenance of a non-symmetric field. Elsasser developed a mathematical machinery for calculating the variations of a magnetic field in the presence of an assigned motion, and showed that in certain cases the magnetic energy is initially increased by the motion. His machinery could be used to calculate the magnetic field maintained by a given motion if this motion were already known to be able to maintain a magnetic field. Bullard was concerned with the Earth's field, but certain of his ideas can be applied just as well to stellar fields. He suggested a combination of internal motions—non-uniform rotation together with circulations of the type likely to be stimulated by thermal instability—which appeared likely to be able to maintain a magnetic field with an appreciable dipole component; but approximations rendered his argument incomplete.

Dynamo action must certainly be an exceedingly powerful agent for maintaining magnetic fields if able to maintain them at all. But neither Bullard nor Elsasser was able definitely to prove that dynamo maintenance of any steady field in a conducting sphere is possible. A proof of this is urgently needed. For though a variety of elementary arguments suggests that dynamo maintenance is always possible with motions of an appropriate strength, these arguments are suspect because they appear to apply also to the axially symmetric case, in which dynamo maintenance is known to be impossible. Some new idea appears to be needed before dynamo maintenance can be either proved or disproved.

The high conductivity of stellar material, as a consequence of which the lines of force are so nearly frozen into the material, is not altogether an advantage from the point of view of a dynamo theory. As Bondi and Gold have pointed out (**76**), if lines of force were exactly frozen into the material no new lines of force could appear above the surface, and in consequence no indefinite increase of the external field by dynamo action would be possible. This argument does not apply exactly to real stars, because the finite conductivity permits the lines of force to leak slowly across the surface. But it does suggest that great changes in the internal field due to dynamo action will not be accompanied by correspondingly great regular changes in the external field. The internal field may be greatly increased but if so it tends to become irregular. A very great field in one direction at one point tends to be accompanied by very great fields in altogether different directions at neighbouring points, the whole constituting what Walén (**77**) has picturesquely termed a "confusion of magnetic force".

Some authors have suggested that if convection is allowed to have its way freely with a small seed field, the resulting confused magnetic field may be accompanied by an appreciable dipole component observable as an external field. This

does not appear probable if the type of convection is completely unaffected by the magnetic field. Quite apart from the slowness of leak of lines of force across the surface, one does not expect an irregular cause to build up to give a regular effect. The mechanical effects of the magnetic field must, however, modify the type of convection somewhat (**85**), so that more regular consequences may be possible. The possibility requires a more detailed discussion.

To summarize this account of theories of stellar fields, the dynamo mechanism is the most powerful of all the agencies studied, if it is able to maintain the fields at all. Other theories rest far more on assumptions about the remote past, or unobservable regions of space; the dynamo theory makes few assumptions, but is beset by more serious mathematical difficulties. Much more work is required to clarify the situation; so far no suggestion has proved wholly acceptable.

Magnetic variables.—Two different theories have been proposed to account for the magnetic spectrum variables such as α^2 C Vn. The lines of force being nearly "frozen" into the stellar material, in the few days' period of a variable the lines of force crossing the star's surface cannot vary appreciably. Hence magnetic variations must be due either to the transport of lines of force from the invisible hemisphere to the visible, and vice versa, or to variations in the angles which the lines of force make with the line of sight. The oblique rotator theory supposes the field to be carried round by the rotation of the star, the axis of rotation being oblique to the line of sight and not coinciding with the magnetic axis. The magnetic oscillator theory supposes the surface layers to describe a regular oscillation in which the lines of force are carried to and fro along the star's surface, and their directions of presentation to the observer are altered.

The oscillator theory has its roots in analogy with the Sun, which as we know undergoes a magnetic cycle of 22 years' duration which affects many of its atmospheric phenomena, including the magnetic polarities and the positions of sunspots, the form of the coronal streamers, and, quite possibly, its dipolar field as well. To develop a crude model of an oscillating star that represents the complexities observed in both α^2 C Vn and HD 125248 is not altogether impossible, though the result appears artificial. In the model studied by Schwarzschild (**78**) the star is supposed to be seen nearly pole-on and to oscillate between prolate and oblate spheroidal configurations. A more detailed discussion shows that the changes in ellipticity are of minor importance, the main feature being horizontal motions towards or away from the poles. Schwarzschild neglected rotation, but if this is taken into account the oscillation includes torsional motions as a result of conservation of angular momentum. The reversal of the effective magnetic field is supposed to result from coherent changes in direction of the lines of force in the atmosphere, while a zonal stratification of certain elements must be assumed to explain the spectrum changes.

Schwarzschild's theory meets with serious difficulties (**79, 80, 81**). Some of these concern the period: while free periods of the right order of magnitude can be found, these do not correspond to the more important oscillations of the star, and it is difficult to understand why oscillations just of these periods should be excited. Even more serious difficulties are met when a detailed explanation of the reversal of the observed field is attempted. The lines of force crossing the observed hemisphere must remain unaltered during the oscillation; also because mechanical considerations forbid any appreciable electric current from

flowing in the star's atmosphere, the field observed is essentially the field, derivable from a magnetic potential, which exists in outer space. These two facts alone are enough to make a reversal of the observed field nearly incapable of explanation by oscillations of Schwarzschild's type. All that can be expected from such oscillations is a limited periodic fluctuation in the field, without change of sign.

Nevertheless, certain features of the magnetic variable stars do suggest oscillations, though not harmonic oscillations—notably the changes in radial velocity, and the very sudden reversal of magnetic polarity (in one-tenth of the period) in α^2 C Vn (Fig. 4). Moreover, the analogy between the solar cycle and the magnetic variations in such stars as HD 188041 (Fig. 3) is decidedly suggestive. If oscillations actually cause the reversal of observed fields this is presumably because they transport alternately patches of positive and negative polarity from the invisible hemisphere to the visible. For example, one might envisage an undisturbed field whose axis is nearly perpendicular to the line of sight, twisted in a sort of torsional oscillation (cf. (**77, 82**)) about an axis perpendicular both to the magnetic axis and to the line of sight. But the possibility of such oscillations, and the associated periods, still remain to be investigated.

The oblique rotator theory assumes that the star has no equatorial acceleration. This is no disadvantage from the theorist's standpoint, for equatorial acceleration always introduces grave theoretical complications when a magnetic field is present (**83**): but it may appear arbitrary to an observer, in view of the evidence that the Sun has both an equatorial acceleration and a general magnetic field. The theory provides a simple mechanism for the reversal of the observed field; to explain the anharmonic nature of the variations of the field, however, the rotating field has to be supposed to deviate from a dipole field to an unknown but very great extent. At the time of writing, the theory has gained support from the work of Deutsch (**84**) who has found observationally a reciprocal relationship between line width and period in several spectrum variables. Such a relationship appears harder to explain on the oscillator theory. Deutsch also finds that the observed profiles of selected lines are, within the errors of observation, the rotational profiles to be expected if the star is rotating about an axis perpendicular to the line of sight with a period equal to that of the spectrum variations; the unknown radius of the star is assumed equal to the average value for stars in its spectral class.

The theory is subject to fewer theoretical objections than the oscillator theory, though this may in part be because it has been studied less closely. Certain difficulties appear to affect it, however, notably the difficulty of explaining the observed variations in the radial velocity. There is also the fact that in α^2 C Vn there would appear to be a concentration of Eu II near the negative magnetic pole, with Cr near the positive pole, while in the otherwise similar star HD 125248 this concentration of the same elements is just the reverse as regards magnetic polarity. There is indeed no obvious reason why atoms of any particular element should be associated with one polarity rather than the other. It would be more credible to assume, say, that in both stars Eu is concentrated in regions of strong field (the poles) and Cr in regions of weak field (low latitudes); but though this may explain the observed phenomena on certain forms of the oscillator theory, it cannot explain them on the rotator theory.

The decision between the two theories must ultimately be made on observational grounds, but first theoretical work must be done to decide the consequences

of each theory and the ancillary hypotheses needed to make each work. For this reason the solution of the problem of the magnetically variable stars presents challenges to both the observer on the one hand and the theoretician on the other.

References

(1) G. E. Hale, *Ap. J.*, **38,** 27, 1913.
(2) G. E. Hale, F. H. Seares, A. van Maanen and F. Ellerman, *Ap. J.*, **47,** 206, 1918.
(3) F. H. Bigelow, "The Solar Corona", Smithsonian Institution, 1889.
(4) H. C. van de Hulst, *Bull. Astr. Inst. Netherlands*, **XI,** No. 410, 135, 1950.
(5) A. Hansky, *Pulk. Mitt.*, **1,** No. 10, 121, 1906.
(6) H. Ludendorff, *Sitz. Preuss. Ak. d. Wiss.*, **10,** 185, 1928; **16,** 200, 1934.
(7) H. W. Babcock and H. D. Babcock, *Publ. Astr. Soc. Pac.*, **64,** 282, 1952.
(8) W. S. Adams, *Ap. J.*, **93,** 11, 1941.
(9) H. W. Babcock, *Ap. J.*, **105,** 105, 1947.
(10) F. H. Seares, *The Observatory*, **43,** 310, 1920.
(11) C. C. Kiess and W. F. Meggers, *Bureau of Standards, Research Paper No.* 23, 1928.
(12) Sylvia Burd (unpublished).
(13) H. H. Plaskett, *M.N.*, **112,** 177, 1952.
(14) R. W. Wood, quoted by G. E. Hale (**1**).
(15) G. E. Hale, *Ap. J.*, **28,** 315, 1908.
(16) G. E. Hale, *Ap. J.*, **49,** 153, 1919; *Nature*, **113,** 105, 1924.
(17) G. E. Hale and S. B. Nicholson, "Magnetic Observations of Sunspots 1917–1924", *Pt. I, Carn. Inst. Wash.*, 1938.
(18) H. D. Babcock and H. W. Babcock, *Journ. Opt. Soc. America*, **41,** 776, 1951.
(19) *Ann. Report Mt. Wilson Obs., C.I.W. Yearbook*, 1932, p. 149.
(20) J. Evershed, *M.N.*, **93,** 96, 1933.
(21) *Ann. Report Mt. Wilson Obs., C.I.W. Yearbook*, 1935, p. 171.
(22) R. M. Langer, *Publ. Astr. Soc. Pac.*, **48,** 208, 1936.
(23) G. E. Hale, *Nature*, **136,** 703, 1935.
(24) *Ann. Report Mt. Wilson Obs., C.I.W. Yearbook*, 1933, p. 143.
(25) *Ann. Report Mt. Wilson Obs., C.I.W. Yearbook*, 1934, p. 138.
(26) *Ann. Report Mt. Wilson Obs., C.I.W. Yearbook*, 1949, p. 12.
(27) *Ann. Report Mt. Wilson Obs., C.I.W. Yearbook*, 1940, p. 9.
(28) H. D. Babcock, *Ap. J.*, **66,** 307, 1927.
(29) H. D. Babcock, *Pub. Astr. Soc. Pac.*, **60,** 244, 1948.
(30) H. von Klüber, *M.N.*, **111,** 2, 1951.
(31) G. Thiessen, *Ann. d'Astrophys.*, **9,** 101, 1946.
(32) G. Thiessen, *Zs. f. Astrophys.*, **30,** 185, 1952.
(33) *Ann. Report Mt. Wilson Obs., C.I.W. Yearbook*, 1951, p. 25; K. O. Kiepenheuer, *Ap. J.*, **117,** 447, 1953.
(34) B. Billings, *Journ. Opt. Soc. America*, **39,** 797, 1949.
(35) S. Rosseland, *Theoretical Astrophysics*, Ch. XIV, Oxford, 1936.
(36) M. Minnaert, *The Observatory*, **60,** 292, 1937.
(37) M. Schwarzschild, *Ap. J.*, **112,** 222, 1950.
(38) H. W. Babcock, *Ap. J.*, **108,** 213, 1948.
(39) A. J. Deutsch, *Ap. J.*, **105,** 283, 1947.
(40) H. W. Babcock, *Ap. J.*, **114,** 1, 1951.
(41) H. W. Babcock and S. Burd, *Ap. J.*, **116,** 8, 1952.
(42) P. W. Merrill, *Ap. J.*, **113,** 605, 1951.
(43) H. W. Babcock, *Pub. Astr. Soc. Pac.*, **62,** 277, 1950.
(44) P. W. Merrill, *Ap. J.*, **65,** 286, 1927.
(45) R. E. Wilson, *Pub. Astr. Soc. Pac.*, **62,** 14, 1950.
(46) G. Gjellestad and H. W. Babcock, *Ap. J.* (in press).
(47) H. W. Babcock and S. Burd, *Pub. Astr. Soc. Pac.*, **63,** 81, 1951.
(48) H. W. Babcock, *Ap. J.*, **110,** 126, 1949.
(49) O. Struve and P. Swings, *The Observatory*, **64,** 291, 1942.
(50) O. Struve and P. Swings, *Ap. J.*, **98,** 361, 1943.

(51) D. W. N. Stibbs, *Nature*, **165**, 195, 1950.
(52) A. Schuster, *Proc. Phys. Soc.*, **24**, 121, 1912.
(53) D. Brunt, *Ast. Nach.*, **196**, 169, 1913.
(54) S. J. Barnett, *Rev. Mod. Phys.*, **7**, 129, 1935.
(55) H. A. Wilson, *Proc. Roy. Soc.* A, **104**, 451, 1923.
(56) P. M. S. Blackett, *Nature*, **159**, 658, 1947.
(57) H. W. Babcock, *Pub. Ast. Soc. Pac.*, **59**, 112, 1947.
(58) S. K. Runcorn, A. C. Benson, A. F. Moore and D. H. Griffiths, *Phil. Trans.* A, **244**, 113, 1951.
(59) P. M. S. Blackett, *Phil. Trans.* A, **245**, 309, 1952.
(60) E. A. Milne, *M.N.*, **110**, 266, 1950.
(61) A. Gião, *Phys. Rev.*, **76**, 764, 1949.
(62) T. G. Cowling, *M.N.*, **105**, 166, 1945.
(63) W. A. Hiltner, *Ap. J.* **109**, 471, 1949.
(64) J. S. Hall and A. H. Mikesell, *A.J.*, **54**, 187, 1949.
(65) P. A. Sweet, *M.N.*, **110**, 69, 1950.
(66) L. Spitzer and J. W. Tukey, *Ap. J.*, **114**, 187, 1951.
(67) L. Davies and J. L. Greenstein, *Ap. J.*, **114**, 206, 1951.
(68) T. Gold, *M.N.*, **112**, 215, 1952.
(69) A. Schlüter and L. Biermann, *Zs. f. Naturforschung*, **5a**, 237, 1950.
(70) L. Biermann, *Zs. f. Naturforschung*, **5a**, 65, 1950.
(71) F. Hoyle, *Some recent researches in solar physics*, Cambridge, 1949, p. 122.
(72) J. Larmor, *Brit. Ass. Rep.* 1919, p. 159.
(73) T. G. Cowling, *M.N.*, **94**, 39, 1934.
(74) W. M. Elsasser, *Phys. Rev.*, **69**, 106 and **70**, 202, 1946 ; **72**, 821, 1947.
(75) E. C. Bullard, *Proc. Roy. Soc.* A, **197**, 433, 1949.
(76) H. Bondi and T. Gold, *M.N.*, **110**, 607, 1950.
(77) C. Walén, *Ark. f. Mat., Ast. o. Fys.*, **33A**, No. 18, 1946.
(78) M. Schwarzschild, *Ann. d'Astrophys.*, **12**, 148, 1949.
(79) Miss G. Gjellestad, *Pub. Inst. Theor. Astrophys.*, Blindern-Oslo, 1950.
(80) V. C. A. Ferraro and D. J. Memory, *M.N.*, **112**, 361, 1952.
(81) T. G. Cowling, *M.N.*, **112**, 527, 1952.
(82) C. Walén, *On the vibratory rotation of the Sun*, Stockholm, 1949.
(83) V. C. A. Ferraro, *M.N.*, **97**, 458, 1937.
(84) A. J. Deutsch (in press).
(85) S. Chandrasekhar, *Phil. Mag.*, **43**, 501, 1952.

SOLAR ACTIVITY

Sunspots.—The progressive decline of the solar cycle towards minimum is continued by the waning sunspot occurrence of 1952. However, the minimum epoch itself may not occur for another 1½ or 2 years, because (1) no high-latitude spots have yet appeared as precursors of the new cycle; (2) the usual steep rise preceding minimum in the number of spotless days has apparently not yet begun; and (3) the mean daily sunspot " number " of 31 for the year is well above the mean value 5·0 (range 1·4 to 9·6) for the seven preceding minimum years.

The sunspot number of 31 compares with 69½ for 1951 and is one-fifth of that for the high maximum year (1947) of the present cycle. It represents a succession of spots—none of great size, but at least a dozen reaching or exceeding an area of 500 millionths of the Sun's hemisphere on one or more days of their respective disk passages. Two groups with central meridian passages July $15^{d}\cdot1$ and November $21^{d}\cdot9$ U.T. reached 1000 millionths, the former spot, nearly on the Sun's equator, rising to 1300 millionths.

Without exception all these spots were subnormal in solar flare frequency. No very intense flare appears, in fact, to have occurred during the year, although a few flares of moderate intensity were either directly observed or detected from their ionospheric effects, producing short-wave fade-outs and sudden enhancements of atmospherics recorded on very long radio wave-lengths.

An interesting feature of the past eighteen months has been the frequent appearance of small, short-lived and usually isolated flecks of polar faculae, centred at about 70° latitude. The occurrence in earlier cycles of similar high-latitude flecks is indicated in Plate 3, *Monthly Notices*, **84,** 96, 1923. The frequency of polar flecks appears to have increased around the intervening sunspot minima of 1923, 1933 and 1944 not covered by the above diagram.

Geomagnetically, the year 1952 was an active one, including nineteen small storms (minimum range at Abinger of 30′ in D or 150γ in H or in V) and one storm exceeding twice this minimum range. This " great " storm on April 21–22 may be associated with a sunspot of maximum area 800 millionths that crossed the central meridian on April $18^{d}\cdot5$ in south latitude 10°. Apart from this storm and three of the small storms with " sudden-commencement " onset, the remaining fifteen disturbances were of the M-region or 27-day recurrence type. Such disturbances are characteristic of the present phase of the sunspot cycle. Some connection is suggested between a very long coronal streamer, recorded at the total eclipse of 1952 February 25, and the occurrence of one of the 27-day sequence storms commencing about March 3 and reaching its maximum on March 5 (*The Observatory*, **72,** 208 and 236, 1952).

H. W. NEWTON.

Prominences.—The mean daily areas and numbers of calcium prominences at the limb as derived from photographs taken at Kodaikanal are given below :—

	Area in (sq. minutes)			Number		
1952	North	South	Total	North	South	Total
January–June	1·15	1·20	2·35	4·15	3·23	7·38
July–December	1·15	1·13	2·28	5·19	4·34	9·53
Whole year (weighted mean)	1·15	1·17	2·32	4·63	3·75	8·38

Compared with the previous year's values, prominence activity as represented by areas shows a decrease of 16 per cent, while the numbers indicate an increase of 23 per cent.

The distribution of areas in 5° ranges of latitude shows maximum activity in the zones N. 10°–15°, N. 25°–30° and S. 35°–40°. A comparison with the distribution in 1951 reveals that in the north, in addition to the peak of activity at 25°–30° persisting since last year, another low-latitude maximum has developed at 10°–15° and in the south the zone of maximum activity has shifted by 15° towards the equator. As in the previous year, practically no activity was observed in the high latitudes beyond 55° in both the hemispheres. The east–west distribution of prominences showed that areas were in excess on the west limb while the numbers were evenly distributed on either side.

Doppler shifts of the H-alpha line in prominences were observed on 5 occasions with the prominence spectroscope. Of these, 3 were in the northern hemisphere; 3 were observed on the east limb.

The heights of 24 prominences in H-alpha, D_3 and H-beta lines were measured with the prominence spectroscope. These were compared with the corresponding heights in the *K* line as obtained from the spectroheliograms. The average heights were 66″·9 in *K*, 63″·2 in H-alpha, 59″·4 in D_3 and 57″·5 in H-beta.

There were 9 occasions during the year when sudden disappearances of hydrogen absorption markings on the disk or of prominences on the limb were observed.

Particulars of Doppler displacements of the H-alpha line in prominences and dark markings observed with the spectrohelioscope are tabulated below :

	Displacements towards			
	Red	Violet	Both ways	Total
Prominences	2	...	18	20
Dark markings	7	3	19	29

The mean daily areas and numbers of hydrogen absorption markings on the disk as obtained from Kodaikanal records are given below :

	Area (in millionths of Sun's visible hemisphere) uncorrected for foreshortening			Number		
1952	North	South	Total	North	South	Total
January–June	1227·2	861·7	2088·9	11·20	7·75	18·95
July–December	915·6	620·5	1536·1	10·89	7·55	18·44
Whole year (weighted mean)	1082·7	747·9	1830·6	11·06	7·66	18·72

Compared with the previous year's value, the mean daily area of the H-alpha absorption markings for the whole year shows a decrease of 35 per cent and the number a decrease of 27 per cent, the values for 1951 being 2815 and 25·76 respectively.

The distribution of areas in 5° ranges of latitude shows peaks of activity in the zones N. 10°–15°, S. 0°–5° and S. 35°–40°. Comparison with the previous year's distribution shows that except for the peak at S. 35°–40°, the chief centres of activity in both the hemispheres have again shifted towards the equator.

As in the case of prominences at the limb, practically no activity of the markings was observed in latitudes higher than 55°. The east–west distribution of the absorption markings shows that both the areas and the numbers are in excess in the western hemisphere. A. K. DAS.

DOUBLE STARS

New pairs.—Finsen (*The Observatory*, **72,** 125) gives new pairs discovered with the interferometer.

Measures.—Measures of double stars are given by Aller and Ferrin (*Urania*, **37,** 1), Baize (*J.O.*, **34,** 116; **35,** 5, 16 and 17), Couteau (*J.O.*, **35,** 101), Danjon (*J.O.*, **35,** 85), Finsen (*U.O.C.*, **6,** 94 and 140), Fokker (*B.A.N.*, **11,** 365), *Greenwich Observations* (1937, p. B2 and 1938, p. B3), Guyot (*J.O.*, **34,** 68), Jeffers (*Lick Bull.*, **20,** 51), Jonckheere (*J.O.*, **35,** 37), Kuiper (*J.O.*, **35,** 36), Muller (*J.O.*, **34,** 81 and **35,** 95), Schmeidler (*A.N.*, **280,** 90) and van den Bos (*U.O.C.*, **6,** 13).

Orbits:

Double Star	*P*	*e*	*a*	Computer	Reference
ADS 684	150	0·54	0·44	Muller	*B.A.*, **16,** 203
,, 755	152·62	0·39	0·989	Rabe	*A.N.*, **280,** 1
,, 862	120	0·6	0·39	Baize	*J.O.*, **34,** 116
,, 1729	35·0	0·63	0·40	van den Bos	*U.O.C.*, **6,** 143
,, 2028	18·0	0·40	0·148	van den Bos	*U.O.C.*, **6,** 11
,, 2236	150	0·55	0·70	Muller	*B.A.*, **16,** 277
,, 2612	287·7	0·70	1·245	Baize	*J.O.*, **35,** 72
,, 2612	192	0·665	1·048	Hopmann	*A.N.*, **280,** 165
,, 3098	161·2	0·420	0·508	Hopmann	*A.N.*, **280,** 167
,, 3159	76·92	0·58	0·500	van den Bos	*U.O.C.*, **6,** 143
,, 3182	55·4	0·71	0·200	van den Bos	*U.O.C.*, **6,** 11
,, 3991 BC	37·0	0·90	0·19	Baize	*J.O.*, **35,** 67
,, 4115	586	0·145	1·293	Siegrist	*Urania*, No. 227
,, 6554	45	0·44	0·47	Muller	*B.A.*, **16,** 203
,, 6871	125·8	0·4	0·56	Vidal	*Urania*, No. 227
,, 7158	57·5	0·30	0·27	Baize	*J.O.*, **34,** 116
,, 7390	119·25	0·545	0·815	Baize	*J.O.*, **34,** 69
,, 7744	260·0	0·49	1·60	Baize	*J.O.*, **35,** 5
,, 7846	211·0	0·790	1·000	van den Bos	*U.O.C.*, **6,** 145
,, 8148	192·00	0·540	1·931	Baize	*J.O.*, **35,** 74
,, 8166	48·40	0·174	0·48	Baize	*J.O.*, **35,** 76
,, 8337	78·97	0·4816	0·380	Wierzbinski	*Acta Astr.*, **5,** 18
,, 8539	678·0	0·946	1·30	Aller	*Urania*, No. 225
,, 8939	54·8	0·80	0·18	Baize	*J.O.*, **35,** 78
,, 8954	195·2	0·90	0·436	Baize	*J.O.*, **35,** 70
,, 9019	720	0·5	1·298	Rabe	*A.N.*, **280,** 1
	450	0·5	1·089		
,, 9352	52	0·10	0·63	Muller	*B.A.*, **16,** 203
,, 9352	51·29	0·0660	0·591	Dommanget	*Ann. Belg.*, **5,** 181
,, 9578	171·43	0·64	1·08	Muller	*B.A.*, **16,** 263
perturbation	50	0·7	0·055		
ADS 9626	260·10	0·59	1·463	Baize	*J.O.*, **35,** 81
,, 10095	88·4	0·23	0·223	Wierzbinski	*Acta Astr.*, **5,** 18
,, 10425	87·0	0·80	0·24	Baize	*B.S.A.F.*, **66,** 74
,, 10598	46·08	0·1745	1·02	Duncombe and Ashbrook	*A.J.*, **57,** 92

Double Star		*P*	*e*	*a*	Computer	Reference
ADS 11046		87·85	0·50	4·551	Strand	*A.J.*, **57,** 97
,, 11479		190·8	0·8175	0·418	Arend	*Ann. Belg.*, **5,** 161
		168·4	0·7799	0·385		
,, 12880		363·82	0·131	2·07	Giannuzzi	*Contr. Mt. Mario*, No. 176
		371·13	0·142	2·089		
,, 12972		148	0·09	0·566	Muller	*B.A.*, **16,** 277
,, 13944		100	0·30	0·190	Muller	*B.A.*, **16,** 277
,, 15971		...	0·36	3·750	Shodo	*Izv. Odess.*, **II, 1,** 13
,, 15972		44·46	0·415	2·386	Hall	*A.J.*, **57,** 47
,, 15992		70·25	0·31	0·236	Baize	*J.O.*, **35,** 71
,, 16314		54	0·64	0·210	Muller	*B.A.*, **16,** 277
,, 16538		150	0·60	0·86	Muller	*B.A.*, **16,** 203
(pos. 1900) h m °						
1 30·4 −30	AB, C	144·0	0·10	1·575	Eggen	*P.A.S.P.*, **64,** 230
5 56·6 −31		72·0	0·50	0·94	Baize	*J.O.*, **35,** 68
6 05·6 −22		18·95	0·33	0·225	van den Bos	*U.O.C.*, **6,** 145
6 27·4 −50	AB	50·0	0·95	0·46	Eggen	*P.A.S.P.*, **64,** 230
	CD	105·6	0·25	0·535		
14 50·4 −34		37·7	0·90	0·244	Bruwer	*U.O.C.*, **6,** 12
17 09·2 +45		12·98	0·73	0·71	Baize	*B.S.A.F.*, **66,** 74

Arend (*Ann. Belg.*, **5,** 147) gives a paper on the correction of the orbit of a visual binary, Deitsch (*Izv. Gl. Poulkovo*, **18,** 5, No. 146) on the orbit and mass of the dark companion of 61 Cyg, Rabe (*A.N.*, **280,** 1) on new methods of orbit determination and correction for visual binaries, Vidal (*Urania*, No. 227) on a variation of Klinkerfuess' orbit method and Mercier (*Publ. Bordeaux*, No. 8 I) on a new method for computing orbits of visual binaries.

Miscellaneous.—Finsen (*U.O.C.*, **6,** 82 and 86) writes on the significance of atmospheric dispersion in astronomical interferometry and on interferometer observations of artificial double stars; Sinton (*A.J.*, **56,** 140) on an achromatic stellar interferometer; van den Bos (*J.O.*, **34,** 85), notes on some series of interferometer measures of double stars; Lacroute and Bacchus (*C.R.*, **234,** 408) on a photoelectric method of measuring double stars; Muller (*B.S.A.F.*, **66,** 213) on errors in magnitude estimates of a visual double star, (*Ann. Strasbourg*, **5,** 5) on magnitudes of components of 315 double and multiple stars, and (*Ann. Astrophys.*, **15,** 79 and *C.R.*, **234,** 812) on colours of 51 double stars; Arend (*Comm. Belg.*, No. 20) on frequency curves and correlations of visual double stars and on the orientation of orbit planes relative to the galactic plane; Boneff (*Annuaire Fac. Sc. Phys.-Math.*, **47,** 1, 1) on the origin of double stars; Opolski (*Arkiv Ast.*, **1,** 249) on the orientation of the orbital planes of visual binaries; Labeur (*C.R.*, **234,** 1129) on the period-eccentricity correlation; Safronov (*A.J., U.S.S.R.*, **28,** 3, 172) on statistics of the physical characteristics of visual double stars; Struve (*Sky & Tel.*, **11,** 302) on the sextuple system of Castor.

Strand and Spong (*A.J.*, **57,** 102) give the parallax and mass ratio of ADS 11046 and Hall (*A.J.*, **57,** 47) of ADS 15972; Ali (*A.J.*, **57,** 146), a note on BDS 9699; and Kent (*A.J.*, **57,** 156) on 48 Cas.

W. H. VAN DEN BOS.

COMETS (1952)

The year was a comparatively quiet one for cometary observations. Although an average number of new comets was discovered, the number of old ones followed was below average and most of them were only within reach of large photographic telescopes. Of the fourteen comets observed, five were new discoveries, of which one had an orbit of short period, one was a periodic comet recovered as predicted, and the remaining eight were comets followed from previous years, including the two "annual" comets.

Of these last two, Schwassmann–Wachmann (1) was observed by G. van Biesbroeck in April, May, and December. It seems to have experienced one of its periodic outbursts of brightness in mid-April, for he recorded it as 15^m on April 23–24, 2′ in diameter. Again on December 23 it was two magnitudes above its normal brightness of around 18^m to which it returned early in the new year. The other, Oterma's comet, was recorded by Van Biesbroeck on April 21 and June 20 as a small image at its normal magnitude, namely around 16–17. No other observations appear to have been made of either of these, despite the plea that Schwassmann–Wachmann (1) should be kept under continuous watch for the study of its physical variations, and the request by P. Herget for frequent observations of the position of Oterma's comet to enable its orbit to be studied with great exactness.

1950 b Minkowski was observed again several times during the year by Van Biesbroeck, and by L. E. Cunningham. In April the image showed the central condensation 8″ in diameter surrounded by a faint coma fanning out to 25″ in position angle 50°, the total magnitude being 16·5 (Van B.). It was still under observation at 19^m at the end of the year, a small round coma 20″ in diameter.

1951 h, the periodic comet Comas Solá, was under observation again from September onwards. At that time it was at perihelion and at its brightest, about 13^m; and on October 18 was described by Van Biesbroeck as having a sharp nucleus, with a slender tail extending 8′ in position angle 295°. Lubor Kresák, who also observed it on that date, speaks of the tail as double. A two-hour exposure he made with the 24-inch Zeiss reflector, at the Skalnaté Pleso Observatory on November 26, showed a tail 15′ long, which is remarkable considering the comet was 1·9 A.U. from the Sun.

1951 i Wilson–Harrington proved a good telescopic object at the beginning of the year for observers in the southern hemisphere. It reached magnitude 6·1 at the end of January and was, in fact, reported by R. Nankivell, an amateur in New Zealand, as just visible to the unaided eye on January 29·4. Similar reports were made by two or three others on succeeding nights. The coma appeared strongly condensed and only about 3′ in diameter, with a tail stretching a degree or more southward. By the end of February the comet had faded to ninth magnitude and was running into the evening twilight. The last reported observations were made visually at Bergedorf on March 14·8 by Max Beyer, who noted the tail 15′ long in position angle 81°, and the total brightness $11^m{\cdot}6$; and photographically at the Yerkes Observatory on March 16 by R. Weitbrecht.

Attempts to record it again in September and October failed (Cunningham, Jeffers).

1951 j, Arend's short-period comet, was followed by Cunningham and Van Biesbroeck till April 24. It was remarkable in continuing for so long to show a tail, with hardly any coma or nucleus. Even when the comet was of nineteenth magnitude there was still a faint tail 30″ long.

1951 k, Harrington's short-period comet, was still about $12\frac{1}{2}^{m}$ in mid-January though fading slowly. W. H. Steavenson on January 16–18 described it as being 1′ in diameter with a faint extension in position angle 50°–60° and with a stellar nucleus of about fifteenth magnitude. The last reported observation, by Van Biesbroeck on April 24, described it as a diffuse coma with a broad tail 1′·5 long in position angle 110°, and gave the total brightness as 14^{m}.

This comet has been called " Wolf–Harrington " on the assumption of its identity with the periodic comet Wolf (2) 1925 I (previously 1924 XII). A. Przybylski, after revising the orbit of Wolf (2) and applying Tisserand's criterion, now agrees with Cunningham in considering identity very probable. However, it seems advisable not to adopt the designation P/Wolf–Harrington till the evidence for identity is more firmly established.

1951 l, Schaumasse's periodic comet, had brightened to ninth magnitude at the beginning of the year and reached sixth magnitude at the end of January when a few observers reported it just visible to the unaided eye. It was widely observed and it is worth noting that at that time the estimates of brightness varied between 5^{m} and $8\frac{1}{2}^{m}$ depending, it seems, on the amount of coma that could be distinguished. Owing to the nearness of the comet to the Earth ($\Delta = 0{\cdot}3$ A.U.), in opposition near perihelion, it appeared as a very diffuse object of considerable size. Photo-electric observations by William Liller at the Ann Arbor Observatory on February 24 detected the coma extending as far as about 80′ from the nucleus. This would represent a diameter of 1·3 million miles. The maximum diameter reported by visual observers with small telescopes and binoculars was about 20′. The coma appeared moderately condensed, containing a stellar nucleus of around thirteenth magnitude (Beyer, Steavenson). Few observers saw much of the tail for, as would be expected with the comet nearly in opposition, it appeared foreshortened and involved with the general coma. Nevertheless Beyer noted it on January 18·9 as 1° in length, slender and straight, in position angle 260°. During March the comet started to fade and by May had reached tenth magnitude. The last reported observation was by Van Biesbroeck on June 24, when the comet appeared as a diffuse " nucleus " of 15″ diameter in a barely noticeable coma, the total brightness being 17^{m}.

The dates of the last known observations of position in 1952 of these comets of previous years are summarized in Table I.

1952 a, the first comet discovery of the year, was made by Robert G. Harrington and Albert G. Wilson on a sky survey plate taken in Virgo, on the border of Coma Berenices, on January 30·5 with the 48-inch Schmidt at Mount Palomar. It was a diffuse object with but little condensation, and had a very short tail. Its total brightness was only 15^{m} and it was already fading, so it could not be followed for long and only a few observations of it were obtained. It proved difficult to photograph owing, it seems, to the lack of central condensation in the coma and the faintness of the nucleus. Cunningham

TABLE I

Last known Observations of Position of Previous Year's Comets

Comet		Date	Mag.	Observer	Remarks
		1951			
1925 II	P/Schwassm.-Wachm. (1)	Dec. 23	16	Van Biesbroeck	
1942 VII	P/Oterma	June 20	17	,,	Nearly stellar
1950 b	Minkowski	Dec. 23	19	,,	Coma 20″
1951 h	P/Comas-Solá	Dec. 21	14	Boyer	
1951 i	Wilson-Harrington	Mar. 16	12	Weitbrecht	Nearly stellar
1951 j	P/Arend	Apr. 24	19	Van Biesbroeck	Tail 30″
1951 k	P/Harrington	Apr. 24	14	,,	Tail 1½′
1951 l	P/Schaumasse	June 24	17	,,	15″ diam.

remarked that on February 21, with the 100-inch reflector at Mount Wilson, the comet was only as easy to photograph as a star of magnitude 19·3 but as easy to see as one of 15·8. This latter figure is more in accord with the value 15^m given by the Schmidt plates taken at Palomar, and agrees with D. Martinoff's estimate that the comet was somewhat fainter than 15^m on February 17–19, on photographs taken with the 15-inch Schmidt ($f/2·4$) at the Engelhardt Observatory (Kasan).

The discoverers themselves obtained the last observations of it on April 16 and 19, by which date the brightness had decreased to 19^m or 20^m. The orbit was found to be that of a short-period comet, but the uncertainty in the period (6·4 years), determined from few observations over so short an arc, makes it unlikely that this faint object will be recovered at its next return.

1952 b was the periodic comet Grigg–Skjellerup which was recovered almost exactly in the position predicted by Cameron Dinwoodie. The first news of its recovery came from Albert Jones in New Zealand, who observed it visually on March 25·7 and described it as a diffuse coma, about 3′ in diameter but somewhat elongated in position angle 80°, and moderately condensed, 12^m. It was reported later that it had already been photographed by Jacobus A. Bruwer with the Franklin–Adams camera at Johannesburg on March 6 and 9. Few observations were obtained of this comet, the last reported being by Van Biesbroeck between April 20 and 24, when it was 14^m, after which it ran into the evening twilight.

1952 c was discovered in Andromeda by Antonín Mrkos on April 28·0 during one of his routine searches with Somet binoculars (100 mm, ×25) at the Skalnaté Pleso Observatory in the Tatra mountains of Czechoslovakia. Owing to its slow motion at the time, he could not verify it till he recovered it on May 15·0. It appeared on May 17 as an oval object of about 5′ diameter showing but little central condensation, the integrated magnitude being about 9·7 (Merton). A few days later observers noted an extension of the coma, or a tail, extending some 6′ southwest. The comet brightened to eighth magnitude in mid-July, when too it showed a nucleus $12^m·3$ excentrically placed in the N.W. part of the coma (Beyer). It then faded slowly and was last recorded by Bruwer at Johannesburg on August 13·7 when it was $13\frac{1}{2}^m$, and by Bobone at Cordoba on August 25·0. Martín Dartayet tried, unsuccessfully, to photograph it on

September 17 with the 60-inch reflector at Bosque Alegre, and considered it must then have been fainter than $17\frac{1}{2}^m$.

1952 d was found in Ursa Minor during a regular search for comets by Leslie C. Peltier of Delphos, Ohio, with his 6-inch refractor of 48-inches focal length ($\times 30$), on June 21·1. This was his eleventh discovery since he started regular searches thirty years ago.* He described it as a typical tenth-magnitude tail-less comet. During the following two or three weeks it brightened to about ninth magnitude showing a round coma 4′ to 5′ in diameter. Steavenson on July 27 remarked the central $1\frac{1}{2}'$ brightened rather sharply and contained a stellar nucleus of magnitude 13·5. Thereafter it faded slowly but at the same time became, for a while, larger and more diffuse. Beyer noted too that the brightness was fluctuating irregularly during July and August. The comet was last recorded with certainty, at around 18^m, by H. M. Jeffers with the 36-inch Crossley reflector at Lick on November 20, as a faint coma with nearly stellar nucleus, and by L. E. Cunningham with the 60-inch reflector at Mount Wilson on November 22.

1952 e, another discovery on plates taken for the National Geographic sky survey with the 48-inch at Mount Palomar, was found in Cepheus by Robert G. Harrington on August 18·3. The original observation stated its magnitude to be 15, but Wirtanen and Miss Roemer, recording it two days later with the 20-inch astrograph at Lick, found its image a nuclear condensation, $16^m{\cdot}5$; while Steavenson observing it visually with his 30-inch reflector on August 23 described the coma as round, 1′ in diameter with a very diffuse edge and somewhat condensed centrally, about 13^m. It brightened and increased in size, Max Beyer on December 18·7 noting the coma as 10′ in diameter, round and well condensed with a nucleus $12^m{\cdot}0$, the total brightness being then $8^m{\cdot}4$. It was still under observation, at around that brightness, in the new year.

A trail of cometary appearance, indicating an object of fourteenth magnitude with a daily motion of 50′, was reported by Lubor Kresák to have been found on a plate taken by him for the periodic comet Comas Solá, 1951 h, at the Skalnaté Pleso Observatory on October 18·1. As no observations could be obtained that confirmed the presence of another comet, no designation was given to this object.

1952 f, the fifth cometary discovery by Antonín Mrkos, and his second this year, was found by him in Virgo during a routine comet search at Skalnaté Pleso on November 28; but again the discovery could not immediately be confirmed. After a period of bad weather, he recovered the comet himself on December 9. By then it was a little brighter, at 10^m, a diffuse object with some central condensation showing, on photographs by Kresák, a short tail. It moved southward and was under observation in the southern hemisphere during December, and in the new year, the coma being by then more strongly condensed, 4′ in diameter and of eighth magnitude (A. Jones).

During the year unsuccessful searches are reported to have been made for the periodic comets du Toit-Neujmin–Delporte (1941 VII) and Pons–Brooks (1884 I). In the former case the comet was due at perihelion in September, and the areas along the paths of both the predictions, by Miss N. Boeva from her own elements for 1941 and by R. Luss from P. Naur's 1941 elements,

* Peltier was recognized as an independent discoverer of 1943 II Daimaca, in addition to the nine others that have included his name in their designations—ref. *P.A.S.P.* **56**, 58, 1944.

were covered in searches by Van Biesbroeck, H. L. Giclas, and L. Kresák; and visually by Albert Jones. In the case of Pons–Brooks, perihelion passage was not due till 1954 May 27 but the comet was expected to have reached seventeenth magnitude by the end of the year under review, and attempts to record it in the positions predicted by Paul Herget were therefore made from July onwards by Van Biesbroeck, H. M. Jeffers, and L. Kresák. It was concluded that the comet was still fainter than 18^m in December.

TABLE II. *The Elements*

Comet		T (U.T.)	q	e
1928 III	P/Crommelin	1928 Nov. 4·9984	0·744955	0·919018
1930 V	Forbes	1930 May 10·4376	1·152800	1·0
1935 III	P/Schw.-Wach. (2)	1935 Aug. 28·5958	2·094675	0·393868
1937 IV	Whipple	1937 June 20·0614	1·733795	1·000160
1939 I	Kozik-Peltier	1939 Feb. 6·8535	0·716496	0·995103
1944 IV	van Gent	1944 July 17·6172	2·225930	1·001995
1945 II	P/du Toit (2)	1945 Apr. 18·7103	1·249747	0·587519
1950 b	Minkowski	1951 Jan. 15·0449	2·572318	1·000855
1952 a	P/Harringt.-Wilson	1951 Oct. 30·370	1·66524	0·51597
1951 i	Wilson-Harrington	1952 Jan. 12·9474	0·740426	0·999820
1951 k	P/Harrington	1952 Feb. 6·6923	1·599252	0·541319
1951 l	P/Schaumasse	1952 Feb. 10·6574	1·194195	0·705648
1952 b	P/Grigg-Skjellerup	1952 Mar. 11·123*p*	0·855618	0·703598
1952 c	Mrkos	1952 June 8·6722	1·282517	0·981763
1952 d	Peltier	1952 July 15·2577	1·202005	1·0
1952 e	Harrington	1953 Jan. 5·3934	1·664974	0·986921
1952 f	Mrkos	1953 Jan. 24·8635	0·777690	1·0
		Jan. 24·8573	0·777749	1·000660

REFERENCES AND NOTES TO TABLE OF ELEMENTS

1928 III P/Crommelin, formerly called P/Pons-Coggia-Winnecke-Forbes. (1) J. G. Porter, MS. Improved preliminary elements from 19 observations covering 29^d, forming 3 normals, perturbations included. Osc. epoch 1928 November 20·0 U.T.

1930 V Forbes. (2) Erich Senftl, *Mitt. Univ.-Sternw. Wien*, **5**, No. 13, 138, 1952. Definitive parabola, from 54 observations covering 50^d. Osc. epoch 1930 June 6·0 U.T. A general solution (p. 141) gave $e = 0{\cdot}996 \pm 0{\cdot}002$ but, owing to the short length of observed arc, the difference from unity has little significance and the residuals are not much improved.

1935 III P/Schwassmann-Wachmann (2). (3) Hans Q. Rasmusen, MS. Definitive, from 16 normal places 1929–42. Osc. epoch 1935 October 5·0 U.T.

1937 IV Whipple. (4) Gheorghe Chiș, *Bul. Ști., Seria Mat. Fiz. Chim.*, **2**, No. 2, 164, 1950, Roumania; *Pub. Obs. Astr. Cluj.*, No. 7. Definitive, from 381 observations covering 263^d. Osc. epoch 1937 June 19·0 U.T.

1939 I Kozik-Peltier. (5) Antoni Przybylski, MS. Definitive, from 562 observations covering 92^d. Osc. epoch 1939 February 26.

1944 IV van Gent. (6) Antoni Przybylski, *U.A.I.C.* 1362. Improved orbit from 10 observations covering 393^d.

1945 II P/du Toit (2). (7) K. Furukawa, *U.A.I.C.* 1368. Definitive, from 9 observations, the only available, covering 49^d.

The comets under observation early in the new year (1953), in addition to the two annual ones, were :

1950 b	Minkowski	1952 e	Harrington
1951 h	P/Comas Solá	1952 f	Mrkos

Table II, giving the elements of cometary orbits, is arranged as in previous reports (*q.v.*) : the symbol P/ indicates a periodic comet, and *p* after the perihelion date that the elements were predicted ones.

of Cometary Orbits

Period (years)	ω	Ω	i	Equinox	Computer	Ref.	Comet
27·90	195·9263	250·0228	28·8894	1928·0	Porter	1	1928 III
...	320·9746	278·2879	97·0890	1930·0	Senftl	2	1930 V
6·42	116·6535	8·2449	21·4387	1950·0	Rasmusen	3	1935 III
...	107·7251	127·7347	41·5571	1937·0	Chis	4	1937 IV
1770	169·0324	288·7578	63·5205	1939·0	Przybylski	5	1939 I
...	336·9780	202·7995	95·0151	1950·0	Przybylski	6	1944 IV
5·27	201·5213	358·7920	6·9184	1950·0	Furukawa	7	1945 II
...	192·4608	38·1851	144·1497	1950·0	Prêtre	8	1950 b
6·38	342·990	127·861	16·375	1952·0	Cunningham	9	1952 a
...	269·6047	76·2100	152·5324	1952·0	Przybylski	10	1951 i
6·51	186·9141	254·2808	18·5000	1951·0	Przybylski	11	1951 k
8·17	51·8338	86·3808	12·0310	1950·0	Sumner	12	1951 l
4·90	356·3669	215·3810	17·6264	1950·0	Dinwoodie	13	1952 b
590	144·8557	121·6818	112·0222	1952·0	Bobone	14	1952 c
...	96·5894	187·9708	45·5641	1952·0	Cunningham	15	1952 d
1436	191·5664	220·7717	59·0089	1952·0	Dubiago	16	1952 e
...	253·8287	342·9222	97·1795	1953·0	Bobone	17	1952 f
...	253·8216	342·9287	97·1767	1953·0	Itzigsohn	18	1952 f

1950 b Minkowski. (8) P. Prêtre, *U.A.I.C.* 1362. From 7 observations covering 335^d, perturbations neglected.

1952 a P/Harrington-Wilson. (9) Leland E. Cunningham, *U.A.I.C.* 1349. Representing 6 observations covering 22^d.

1951 i Wilson-Harrington. (10) Antoni Przybylski, *U.A.I.C.* 1360. From 22 observations covering 195^d.

1951 k P/Harrington. (11) Antoni Przybylski, *U.A.I.C.* 1360. From 7 observations covering 73^d. It is probably identical with P/Wolf (2), 1925 I.

1951 l P/Schaumasse. (12) Michael Sumner, MS. Improved elements from 22 observations covering 209^d, with perturbations included, and linked to 1944. Osc. epoch 1952 February 10·65 U.T.

1952 b P/Grigg-Skjellerup. (13) Cameron Dinwoodie, *Handbook B.A.A.* 1951 and 1952. Prediction based on Cunningham's elements (*M.N.* **108,** 128, 1948 ; ref. 4). Osc. epoch 1952 March 9·0 U.T. Observations indicated *T* 1952 March 11·1620 U.T.

1952 c Mrkos. (14) Jorge Bobone, *U.A.I.C.* 1380. Representing 34 observations covering 28^d.

1952 d Peltier. (15) Leland E. Cunningham, *U.A.I.C.* 1378. Preliminary elements from 3 observations covering 55^d.

1952 e Harrington. (16) A. D. Dubiago, *Astron. Circ.* (U.S.S.R.) 130. Representing 8 observations covering 29^d.

1952 f Mrkos. (17) Jorge Bobone, *U.A.I.C.* 1390. Representing 10 observations covering 32^d. (18) M. Itzigsohn, *H.A.C.* 1205. Representing 11 observations covering 52^d.

Additional Notes

Individual Comets

1899 I E. Swift. Hans Q. Rasmusen : " On the Original Orbit of Comet 1899 I "; *Pub. Copenhagen Obs.* No. 158, 1952. Working back from C. J. Merfield's definitive orbit, he obtained the original (1871) value $1/a = -0{\cdot}0000270 \pm 0{\cdot}0000184$. A. Wedemeyer (Ref. *A. J. B.* **4,** 173, 188, 1902), however, re-discussed Merfield's results and, had his definitive elements been used, Rasmusen would have got the original $1/a = -0{\cdot}0000072$, which is well within the probable error. It seems therefore that, contrary to Rasmusen's opinion, there is no real evidence for an original hyperbolic orbit.

1932 I Houghton-Ensor. Erna Schrutka-Rechtenstamm : " Definitive Bahnbestimmung des Kometen 1932 I (Houghton-Ensor) ", *Mitt. Univ.-Sternw. Wien,* **5,** No. 14, 143, 1952. The elements were given in the report for 1946 (*M.N.* **107,** 108, 1947 ; ref. 18).

1936 V Hubble. Antoni Przybylski : " Definitive Orbit of Comet 1937 g (Hubble)"; *J. des O.*, **35,** 113, 1952. The elements were given in the last report (*M.N.* **112,** 342, 1952) but the value of Ω, given wrongly in *U.A.I.C.* 1329, is to be corrected to $96^\circ 56' 58''{\cdot}65 = 96^\circ{\cdot}9496$.

1945 III du Toit. The determination of the definitive orbit has been undertaken by Antoni Przybylski (Canberra); *U.A.I.C.* 1362.

1951 l P/Schaumasse. Kenneth Yoss : " Photometric and spectrophotometric observations of Comet Schaumasse "; *A.J.* **57,** 169, 1952.

1952 c Mrkos. The determination of the definitive orbit has been undertaken by Lubor Kresák; *U.A.I.C.* 1365.

P/Wolf (1). M. Kamienski : " Researches on the origin of the Comet P/Wolf I ", Parts V–VI and VII–XI; *C. R. de la Soc. Sci. et Lettres,* Cl. III, 1949 and 1950–51, Warsaw 1952. " Researches on the Motion of Comet P/Wolf I ", Part XVI; *ibid.*, 1951, Warsaw 1952. " The close approach of the Comet P/Wolf I to Jupiter in 1756—Preliminary Results "; extract from *C. R. M. des Séances, Acad. Polonaise,* 1951. He has now investigated the motion of this comet over nearly 200 years. " Reappearance of the Comet P/Wolf I in 1950—Preliminary Results " ; *Acta Astron.* Sér **c, 5,** 1952.

General

F. Baldet and G. de Obaldia : " Catalogue Général des Orbites des Comètes de l'An −466 a 1952 ", *CNRS,* Paris 1952.

Vladimír Vanýsek : " The Photometrical Parameters of New and Old Comets "; *Contrib. Astron. Inst. Masaryk Univ.*, **1,** No. 9, Brno 1952.

Corrigendum

M.N., **112,** 343, Comet 1936 V Hubble. See above.

G. MERTON.

ADDRESS

Delivered by the President, Professor H. Dingle, on Science and Modern Cosmology

It has become the custom in recent years for the President, during his term of office, to address the Society on the department of astronomy in which his own work lies. It is a good custom, but not one which at first sight it seems possible for me to maintain. My subject is the history and philosophy of science, and that can scarcely be called a department of astronomy ; it seems either to lie wholly outside or else to include astronomy as a small part of its concern. In neither case does its claim to your interest on this occasion seem a strong one. Nevertheless, I believe that it is in fact highly relevant to the present position in astronomy. Had that not been so, I should not have been justified in accepting the high office to which you called me two years ago. I propose therefore to explain as best I can why I think this subject is vitally pertinent to the working astronomer of this age.

Of course, in one sense the study of the history and philosophy of science needs no apology in any sphere. Science plays such an essential part in modern life, on both its active and its contemplative sides, that no one can call himself educated who has not some idea of its nature and its history. That I think is indisputable, but it is not so clear that a knowledge of these things is necessary to the actual prosecution of astronomical studies. Science has been advanced in the past by men who have paid little attention to the wider implications of their actions, men who would have been unable to formulate any clear statement of what they were doing, and whose knowledge of the origin and growth of science has been negligible. They have gone forward in the right direction as though by instinct, seeing spontaneously what is legitimate and what is not. And such men have not been exceptional among scientists ; they have been typical. It is not surprising, therefore, though it is regrettable, that there are many even today who hold that the scientist and the philosopher of science are pursuing independent ends and the less they interact the better for the progress of science.

The apparent justification for this view lies, I think, in the peculiar nature of science by which in its earlier stages it has automatically generated within itself its own steering mechanism, so to speak. In the first place, the world has been so full of mysterious phenomena that there has been no temptation to wander outside experience in search of other realms to conquer ; and secondly, it has become almost an intuition with scientists that they must submit their findings to the test of observation at every stage. If a scientist tends to postpone this duty, his neighbour, who holds different views, has always been at hand to perform it for him. Science has thus stood in little danger of violating its own essential principles, and the understanding of what those principles are has been, from the practical point of view, a superfluity. But this state of innocence no longer exists. In cosmology in particular it has almost entirely disappeared. The universe we contemplate today is no longer the observable world that for 2000 years was the sole object of astronomical study ; it is a hypothetical entity of which what we can observe is an almost negligible part. The assertions we

make about it, if susceptible of test at all, require observation over periods of millions of years or in the remote past, and are therefore beyond any sort of practical check. In these circumstances, there is nothing that can control speculation, and preserve legitimate theory from idle fancy, but a strict adherence to the essential principles of science, those principles that in the seventeenth century started the course of ever accelerated progress by which the scientific philosophy is most obviously distinguished from the philosophies that were then its rivals.

In cosmological studies, then, a knowledge of the history and philosophy of science is not a superfluity, it is a necessity. I therefore make no apology for asking you to consider its bearing on the recent revival of interest in this most ancient branch of our subject. I do so the more readily because, although some of the prominent contributors to modern cosmology have unconsciously realized that the nature of science has some special relevance to their researches—witness their frequent appeals to what is " scientific " and what is not, which are not a normal feature of astronomical papers—they betray not only a profound ignorance of the subject, but also a clear lack of any serious reflection on what they are saying. It is as though—as, in fact, I believe to be the case—they are not really concerned to know whether they are being scientific or not, but wish to dignify their own opinions, and discredit opposing ones, by invoking a name that commands general respect. Let me take two examples.

" It is against the spirit of scientific enquiry," says one writer*, " to regard observable effects as arising from ' causes unknown to science ', and this in principle is what creation-in-the-past implies." There are more than one astonishing aspects of this remark. For instance, what conceivable misfortune could have led the writer so to misinterpret both the words and the performances of almost all the great contributors to science as to think that a confession of ignorance is " unscientific ", when in fact one of the chief characteristics of the scientific attitude has always been just that particular type of humility. Galileo recommends his readers " to pronounce that wise, ingenious and modest sentence, ' I do not know ' ".† " The cause of gravity," wrote Newton, " is what I do not pretend to know ".‡ And again, " to derive two or three general Principles of Motion from Phænomena, and afterwards to tell us how the properties and actions of all corporeal things follow from those manifest Principles, would be a very great step in Philosophy, though the Causes of those Principles were not yet discover'd : And therefore I scruple not to propose the Principles of Motion above-mention'd, they being of very general Extent, and leave their Causes to be found out ".§ I refrain from running through the centuries to cite confirmatory evidence, because I must mention a still more astonishing thing. After making this unfortunate remark, the writer proceeds to develop his own idea, which turns out to be precisely what he has just opposed to the spirit of scientific enquiry—namely, that the observable universe was created in the past by causes unknown to science. The natural inference is that he is averse from scientific enquiry and is arguing for a more excellent way, but I do not think that this is the true explanation. I believe that he has a vague feeling that he can confer some

* *M.N.*, **108**, 372, 1948.

† Dialogues on the Two Chief Systems of the World, Fourth Day. (*See* Salusbury's Translation, p. 407.)

‡ *Opera* (Horsley's Edition), iv, p. 437.

§ *Opticks*, Fourth Edition, p. 377.

dignity on his theory if he can stigmatize alternatives as " unscientific ", and without reflecting on what science really is, or on the obvious implications of his own remark, he presses its name into his service for that end.

I pass to my second example. " Experimental science," we read*, " is based on the assumption that the repetition of an experiment will reproduce the original results, and indeed the realm of experimental science is defined by this criterion. " And again, elsewhere, to emphasize the point : " The unrestricted repeatability of all experiments is the fundamental axiom of physical science."† The first thing to notice about this is that experimental science is said to be based on an assumption. It is based on no assumption ; it is an adventure, in which you accept whatever you find, and although you may be guided in a particular case by an expectation, the experiment may reveal something totally different. Schwabe counted sunspots with the idea of finding an intra-Mercurial planet ; instead he found the 11-year solar period, and he would have found exactly the same had he counted the spots with any other object in view, or with none. Does anyone believe that if tomorrow it is discovered that some assumption—any one you like —which has been made in the past is baseless, the achievements of experimental science will suddenly lose all significance ? I do not think so. The " fundamental axiom " goes wrong at the very beginning. But not only is it not the basis of science ; it is patently false, and could not be the basis of anything worthy of acceptance. The most striking example of this is afforded by psychology. It would scarcely be wrong to say that in this science—the emergence of which in recent years is one of the most striking revelations of the great scope of the scientific philosophy—there is no experiment which, when repeated, produces the original result.‡ It would be difficult to conceive of a more crippling restriction on the liberty of modern scientific enquiry than the adoption of this supposed fundamental axiom. But, indeed, one need not go to psychology for evidence. Even in physics, where the writers might have been expected to be more widely informed, it has been the universal belief for the last hundred years that no experiment is repeatable, the entropy of the universe never being twice the same. It can hardly be objected that the universe is irrelevant, because it is precisely to the universe that the supposed axiom is later to be applied, but even on the small scale there are sufficient examples of hysteresis phenomena to have shown the falsity of such a notion to anyone who had stopped to think for a moment. Two apparently indistinguishable pieces of iron are subjected to the same magnetic field and they respond differently ; and the explanation that science gives is that one has been through the process before and repetition gives a different result. In the circumstances it is perhaps not superfluous to say that

* *M.N.*, **108**, 104, 1948.

† *M.N.*, **108**, 252, 1948.

‡ This is accepted so implicitly by psychologists that it is difficult to find an actual statement of it. Professor R. W. Russell, however, has kindly drawn my attention to the following two passages: " The term repetition, as applied to an event of nature, is clearly ideal and non-realizable in any concrete case, like the term equality and the term circle. No two concrete objects in nature were ever ideally equal in every respect. No two experiments on any event of nature were ever ideal repetitions, because nature never repeats herself." (G. Humphrey, *Thinking*, Methuen, 1951, p. 113.) This quite general statement is then shown to have practical importance in particular psychological experiments. The second passage is as follows : " These two constant errors, practice effects and fatigue effects, *are potentially constant errors in almost all psychological experiments, hence, become factors which must be considered in the design of all experiments.*" (B. J. Underwood, *Experimental Psychology*, Appleton-Century-Crofts, 1949, p. 29.) The terms " practice effects " and " fatigue effects " are self-explanatory; " constant error " has a technical meaning.

if it is contended that the pieces of iron are really different, but only appear alike, the whole argument becomes circular. The reason why so many experiments are approximately repeatable is that we take infinite pains to select them from the others, because in the earlier stages of science, in which we are at present, they are easier to interpret than the great majority of possible ones which are scarcely ever repeatable. Our cosmologists have mistaken a commonsense device for an essential principle.

Now I have not given these examples merely to show that the name of science is treated with a casual disrespect unworthy of serious investigators. If that were all they could be ignored. But the position is much worse than that. This last illusion is not merely a casual aside. It is made the basis, and the sole basis, of a sweeping assertion which has been called " the perfect cosmological principle ", for which, with its companion, " the cosmological principle ", enormous claims are made. For example, the cosmological principle has attained the " pre-eminent position in cosmology "*, and " In any conflict between general relativity and the cosmological principle it seems that it is general relativity that must be abandoned "† ; while at the behest of the perfect cosmological principle atoms are created and nebulae vanish from the observable universe. The " cosmological principle ", I should explain, is the assertion that " the universe presents the same aspect from every point except for local irregularities "‡, and the " perfect cosmological principle " states that " apart from local irregularities the universe presents the same aspect from any place at any time ".§ If we ask for evidence for these principles, of the kind that can be accepted as scientific, we see that for the " cosmological principle " there is the fact that so far as the universe has been surveyed—which is probably a very small fraction of its whole extent—there is a rough approximation to uniformity of distribution of matter. This makes it reasonable to assume, for purposes of investigation, that a similar uniformity might characterize the whole, in anticipation of the time when we can compare the implications of the assumption with the wider knowledge that will later become available. For the " perfect cosmological principle ", on the other hand, there is no evidence of any kind at all. Since it causes me considerable discomfort to use names which are clearly misleading, I shall refer to the " cosmological principle " as the *cosmological assumption* and to the " perfect cosmological principle " as the *cosmological presumption*, reserving the right, when the " absolutely perfect cosmological principle " makes its appearance, to introduce the terms " first " and " second " cosmological presumption.

Now we have here a remarkable and a very serious phenomenon. I have no time to discuss the meaning of science, so I will here assert of it only that which I think will command universal assent, namely, that *no statement about the universe, or nature, or experience, or whatever term you prefer for the object of scientific investigation*‖, *shall be made*—let alone advanced as a fundamental

* H. Bondi, *Cosmology* (Cambridge University Press, 1952), hereafter referred to as " H.B.C.", p. 11.

† H.B.C., p. 122.

‡ H.B.C., p. 11.

§ H.B.C., p. 12.

‖ In other connections the distinction between these alternatives is important, but not here. The essential requirement in this Address is to distinguish between that uncontrollable something which we investigate, whatever it may be called, and the mental machinery of investigation, which we can choose freely.

principle—*for which there is no evidence.* What we are faced with now is the quite different claim that *any statement may be made about it that cannot immediately be refuted.* It seems that if you are attracted by an idea for which there is no evidence, all you have to do is to call it a " principle ", and then no evidence is needed. We are told that matter is being continually created, but in such a way that the process is imperceptible*—i.e. the statement cannot be disproved. When we ask why we should believe this, the answer is that the " perfect cosmological principle " requires it. And when we ask why we should accept this " principle ", the answer is that the fundamental axiom of science requires it. This we have seen to be false, and the only other answer that one can gather is that the " principle " must be true because it seems fitting to the people who assert it. With all respect, I find this inadequate.

I want to trace the steps by which it has become possible for what is in fact the contrary of science to present itself as something essentially scientific, and not to be immediately recognized in its true form, but before attempting this I must call attention to another example of the same disconcerting phenomenon, for both will be found to spring ultimately from the same source. I said that in true science nothing is asserted without evidence. I can go a step further, without challenge from any authority of whom I have ever heard, and say that the object of scientific investigation is the world of experience—or, if you like, experience itself—and that all advances in science consist either in enlarging the range of experience or in expressing the regularities found or to be found in it. The new doctrine which I have so far been discussing arises from the substitution for the phrase " expressing the regularities found in experience " of the incompatible phrase " asserting that experience must conform to the tastes of the investigator "; and the other doctrine, which is its twin, arises from the substitution of the phrase " asserting that experience must conform to a pattern which we can deduce by pure reason ". This also has been used to build up an elaborate scheme of cosmology†, and it deserves a little closer examination before we seek to discover how it came to intrude into the scientific domain.

This doctrine is usually expressed in the form that the laws of nature can be derived by reason without recourse to experience.‡ What those who assert it seem to overlook is that, by definition, laws of *nature* are laws followed by that which we experience, not that which we deduce from our axioms. It is therefore self-contradictory to say that laws of nature can be derived without recourse to experience : it is like saying that eggs can be eaten without recourse to eggs. What seems to be meant is that there are some objectively existing mathematical formulae called " laws of nature " which we can arrive at by a process of reasoning, and then, if we look at the world, we shall find that it behaves according to those laws. But suppose it does not, as even the simplest of us may imagine ? Only one of the believers in this doctrine, so far as I know, has attempted to answer this question, and his answer is that in that case we must have made a faulty identification between the *a priori* laws and the corresponding facts of nature.§ But this leaves us no means of knowing when

* H.B.C., p. 143.

† e.g. E. A. Milne, *Modern Cosmology and the Christian Idea of God*, Oxford University Press, 1952.

‡ e.g. A. S. Eddington, *Relativity Theory of Protons and Electrons*, § 16.95, 1936. E. A. Milne, *op. cit.*, p. 33.

§ A. S. Eddington, *The Philosophy of Physical Science*, Chapter VIII, 1939.

we have made the right identification except by an appeal to experience, so we are back at empirical science again; we can derive laws of nature without recourse to experience, but we cannot know that they are laws of nature without recourse to experience.

The fact is that nothing at all can be derived by reason unless you start with certain axioms which in the last resort must be chosen arbitrarily.* Take what seem to be the most obviously necessary of *a priori* truths—the rules of simple arithmetic. Nothing would seem more clearly a truth derived by pure reason than the statement $1-1=0$, and to this, if to anything, we might expect experience inevitably to conform. But does it ? In some things, yes, and in others, no. If you take from me my only sixpence, I have none left ; the law is inexorable with regard to sixpences. But if you take from me my only idea, you are (let us hope) enriched, but I am not impoverished ; I may even acquire another idea in the process. $1-1=$ at least 1 in that case. $1-1=0$ is a truth derivable from certain axioms about numbers, and from other axioms you can derive other conclusions, which you can call " laws of nature " if you wish and which are equally necessary deductions from the premises. But the scientific question is not whether you can derive such laws about the universe, but " is the universe the sort of thing that obeys those laws or is it not ?", and you can answer that only by observing it to see.

We have, then, the strange position that in cosmology two impostors have usurped the throne of science, worn her crown and taken her name. Whereas the source and final court of appeal in science is experience, that of one impostor is personal taste, and that of the other, pure reason. Neither is, of course, new : it was one of the triumphs of the scientific philosophy in the seventeenth century to have apparently routed them both. But they differ in this respect, that the former has never before, to my knowledge, presented itself quite so brazenly as a genuine philosophy ; it has always worn a disguise showing a more respectable aspect. How has it come about that at this relatively advanced stage in the progress of science these pseudo-sciences have again come to life and threaten to deceive the very elect ?

I think the process began with the advent of the theory of relativity. This is ironical, for the essence of that theory lay in the recall of science to experience from which it had unconsciously strayed. Nevertheless, I think we can see how the thing happened. As everyone knows, the solution of certain problems which faced classical physics was found to lie in the fact that some concepts—that of the absolute simultaneity of separated events is perhaps the best-known example—had been assumed to be directly related to experience whereas in fact they were not. On examination it proved that by no physical process was it possible to determine unambiguously whether two such events occurred at the same time or not. Accordingly, in order to establish science on its proper basis—that of experience—such concepts as these were eliminated and experience was described in terms of those concepts alone which had a precise empirical meaning.

The particular error which was thus corrected happened to arise from incomplete consideration of the effects of changing one's coordinate system. Now a coordinate system is an invention of the scientist which facilitates the expression of the regularities which he finds in experience. It is not itself something found

* Eddington chose, among other things, certain " forms of thought ", which in fact are not necessary but have usually been assumed in empirical science. See *The Philosophy of Physical Science*, Chap. VIII.

in experience ; it is a purely imaginary construction which some scientists have tried to do without, but which nevertheless has become firmly established as a part of the physicist's language, so to speak. Before describing physical events it is convenient to choose one particular point in space and one particular instant in time, and to assign to them the number 0. The point-event thus defined is called the *origin* of coordinates. Next, three mutually perpendicular lines (or something equivalent) are imagined to extend indefinitely far, each in both directions, from the origin. These are termed the *axes* of coordinates. They are graduated in any arbitrary way, provided that the graduation numbers increase numerically outwards from the origin in all directions ; and the successive instants of time are enumerated in any arbitrary way, provided that the later of any two instants has an algebraically higher number than the earlier. Finally, the whole system of coordinates is assumed to be moving with some velocity, v, in some direction. Now every element of this coordinate system—the origin, axes, graduation, velocity—is arbitrary, to be chosen as the investigator thinks convenient. It is a fiction, a language in terms of which to express what is observed to happen, but it is itself not something that exists or happens, not a part of the universe or an element of experience. It follows that you can change it as you wish, without affecting in any way at all what is to be described in terms of it, but of course changing the description, just as you do not change the meaning of a sentence when you translate it from English into French, though you change the sounds uttered or the marks made on paper.

Because of this essential arbitrariness it becomes important to understand how to translate descriptions of experience from the terms of one coordinate system into those of another, for only thus can you distinguish, in a particular expression of the laws of nature, what part belongs to the world described and what merely to the language of description. The essence of the theory of relativity consisted in the discovery that it had been wrongly assumed in the past that one particular set of coordinate systems had a unique importance in that it was not, like the others, merely more convenient than its rivals, but was itself a part of nature. All efforts to discover this unique set had failed, said the theory of relativity, because there was nothing to discover, and to safeguard future investigators from making the same error it employed a particular mathematical device, known as the tensor calculus, which automatically ensured that laws of nature expressed in terms of it were exactly translatable from any one coordinate system into any other. From that time onwards it became the fashion to seek a tensor expression for all laws of nature. Indeed, in some respects the thing was overdone, for while it is true that tensor expressions ensure that no coordinate system has preferential treatment, they are not necessarily alone in this, and a proposed law of nature is therefore not necessarily invalid if it is not in tensor form. That, however, is a minor point. The essential thing is that by means of the tensor calculus we can avoid the mistake of ascribing to nature what actually belongs only to the arbitrary machinery for describing nature.

In carrying out the programme thus set up, Einstein arrived at what have been called his " field equations "; they are as follows :

$$G_{\mu}{}^{\nu} - \tfrac{1}{2} g_{\mu}{}^{\nu} G = -8\pi T_{\mu}{}^{\nu}.$$

These are expressions in tensor form of certain regularities found in nature by experiment. The distinction between the expression and what is expressed is perfectly clear. On the right-hand side of the equations you have the relations

which have been found by experience to hold between measured quantities. These could have been derived in no other way than by observation; they are direct statements of the results of observation, and as such are independent of any freedom of choice which the scientist may possess—other than that of refraining from making or examining the measurements, of course. On the left-hand side of the equations you have the expression of these relations in terms of coordinates, and by choosing a tensor expression you ensure that if it holds good in one it will hold good in all such systems, whatever they may be. The observer's liberty is thus wholly confined to the left-hand side, and it is subject only, but inescapably, to the condition that his tensor must in fact express the observations given on the right-hand side. In general, there are a number of tensors that will do this. Pending further knowledge, the observer then chooses the simplest and, if he is wise, remembers that his choice may be wrong. This is what Einstein did, and the essential condition of science was thus preserved. The findings of experience stand first of all in their own right, and the mechanism of description is then chosen with complete freedom so long as that right is not violated. This is known as the general theory of relativity.

At this point it becomes possible to apply the theory to the universe. The first step is to observe the universe and see how it behaves; the second, to find tensors whose mathematical properties correspond to that behaviour. Unfortunately, the first step is possible only in the most rudimentary form. We can observe a little of the region nearest to us; of what lies beyond we know nothing. It is necessary, therefore, if we are to consider the matter at all, to make some assumptions. Einstein assumed that the universe was homogeneous; that is to say, that the region we can observe is a typical sample of the whole. He recognized, of course, that this was an assumption, but the other possibilities were so numerous that it was impossible to choose between them otherwise than by pure caprice, so the assumption of homogeneity was made to see what it would yield. The field equations could then be used to deduce what happened at the places and times corresponding to high values of the coordinates, at present beyond the reach of observation. The deductions would be valid, subject to two conditions: first, that the universe was, in fact, homogeneous, and second, that the tensor chosen for the left-hand side of the equations was, in fact, the right one, so that extrapolation could be made with safety.

I need not describe how Einstein's original model for the universe came to be modified when the systematic recession of the nebulae was discovered, because this introduced no change of principle. What I am seeking is the process by which this essentially scientific procedure became degraded into unscientific romanticizing. I think the first step on the slippery slope was taken when, in the spate of popular expositions of relativity that followed the eclipse observations of 1919, a coordinate system—a somewhat abstruse mathematical conception—was transformed into an "observer", whom the general reader was presumed to be able to picture much more vividly. Instead of comparing two coordinate systems which were equally at the choice of a single observer, two observers were compared, each of whom was supposed to regard himself as being at rest at the origin of his own unique system. I do not think that those who adopted this device can be blamed for its consequences. It is certainly more picturesque than the naked truth, and, provided that the

hypothetical observer is granted no properties that are not possessed by a coordinate system, it is quite legitimate. The expositors could scarcely have foreseen that the coordinate system was soon to be endowed with a mind, with superhuman observing faculties, and with authority to dictate to the poor working scientist what kind of instrument he must restrict himself to and how he must adjust it. But that, in fact, is what happened. In the theory of kinematical relativity* we do not start with observation; we start with a universe full of supposititious observers who must not only be able to construct instruments but must voluntarily choose particular numerical constants—i.e. they must be thinking beings, not merely mechanisms. These observers are essential to the existence of science, for they are necessary to the construction of all measuring instruments; unless they exist and behave in the way laid down for them, science cannot begin. The mere fact that it has begun without their assistance is ignored. The instruments we have in fact used are proscribed because, it is said, they cannot be "defined". The beautifully clear-cut division that relativity made explicit between the world to be observed and described on the one hand, and the coordinate language in which to describe it on the other, is completely obliterated. The coordinate language is transformed into a multitude of intelligences and projected out into the world to be observed. We do not in fact observe them, but that does not matter, for we have already decided how they behave. Our part is to restrict our operations to those which they approve, and the rest of the universe must be such that they all agree about it. If it appears to us to be different from that, so much the worse for us; our observing instruments must be illegitimate, and no account must be taken of their findings.

This seems a long way from the scientific ideal of accepting observations without question and reducing them to order by the free operation of reason, but I think we can see how it has happened. It is true that general relativity made a sharp distinction between the world to be observed and the coordinate systems of our invention, but that distinction was very different from what had previously been supposed. Scientists had long been accustomed to choosing the origin and axes of their coordinate system when and where they liked, but they had always supposed that its motion was not at their choice; it belonged to the world outside. Relativity showed that that was not so, that just as it was impossible to say that one particular place and time afforded the only legitimate observation point, so it was impossible to say that one particular state of motion was so distinguished. A great deal, therefore, of what had previously been thought to belong to nature was shown to belong really to ourselves. Figuratively speaking, Einstein's field equations could be said to have been formed out of their predecessors by a huge transfer of substance from the right- to the left-hand side. This sudden accession of importance to the coordinate system predisposed mathematical physicists to invest it with still greater importance, and its personification as an "observer" pointed the direction of development. It was automatically animated and given rights of its own which the actual observer was not allowed to violate. His instrument thus became a Frankenstein's monster, slipped from his control, and began to dictate to him what he should observe. And this was done in the name of

* See, for example, E. A. Milne, *Relativity, Gravitation and World Structure*, Oxford University Press, 1935, and numerous other writings.

relativity.* It was completely overlooked that the justification for Einstein's action lay in the fact that no physical effects of motion in itself, of " absolute " motion as it is called, were discoverable and that its transfer from nature to the coordinate system was therefore a simple expression of fact. To satisfy the demands of the hypothetical observers, *relative* motion also was transferred to the coordinate system, although the effects of this were observed every day. All that was necessary was to call the time of occurrence of these effects by the symbol τ instead of t, and the thing was done. The imaginary observers were in complete control, and science, its name having been purloined, was left as an outmoded superstition.

It is now but a step to the advent of the second of our two usurpers. The whole foundation of kinematical relativity lies in the existence and potentialities of the army of cosmic observers. They must therefore be established on an unshakeable basis. They are certainly not observed ; hence they must be either imagined or reasoned into existence. Imagination had not then become sufficiently respectable as a basis for cosmology—that was to be reserved for the creators of the cosmological presumption—so it was held that the cosmic observers were required by pure reason. A universe that did not conform to the behaviour prescribed for them was held to be irrational. This universe is not irrational. From this the whole scheme followed, with far-reaching consequences, not only astronomical but even theological.†

It is very difficult to describe this work objectively without giving an impression of satire, but I have no intention whatever of doing so. I have the extremest admiration for the single-minded devotion and superlative mathematical skill which are evident throughout the development of this grandiose scheme, but I find it impossible to describe it in the light of the accepted principles of science without making it appear fantastic. And the reason is simply that it is fantastic. Repeated attempts to call attention to what appear as its fallacies have been futile. They have never been answered, but have simply been dismissed as " trivial " or even " frivolous ".‡ No criticism has been admitted as valid that is not a criticism of the internal consistency of the scheme. The status of its foundations, and its relevance to the traditional object of scientific enquiry, the world of experience, are held to be idle questions. I can only do my best to present it in the clearest possible light against the scientific background, and leave it to be judged in that setting.

I return now to the other violation of science in modern cosmology—that which originated in the cosmological presumption. This also was made possible by the revolution in thought caused by the general relativity theory, and its point of departure is again the wide scope shown to be possessed by coordinate systems. Let me point out once more the fundamental distinction which general relativity acknowledged and emphasized between coordinate systems, which are entirely subjective, entirely under our control, and entirely independent of the

* e.g. E. A. Milne (*Relativity, Gravitation and World Structure*, p. 16): " Relativity and solipsism are incompatibles. Relativity is the complete denial of the solipsist position. " This is said of " relativity " and " kinematical relativity ", as the context makes clear. Actually, of course, relativity has nothing whatever to do with solipsism; if there is only a single observer he can choose his coordinate system as he wishes, and if there are 10^{79} of them, they can do no more. But the passage indicates clearly enough how the purely conceptual coordinate system of relativity had become transformed into a sentient being.

† E. A. Milne, *Modern Cosmology and the Christian Idea of God.*

‡ e.g. *Nature*, **155**, 512, 1945, and, by implication, H.B.C., p. 123.

universe which they are employed to describe, and the universe itself, which is entirely objective, not in the least degree under our control, and remains precisely the same whatever coordinate system we employ for describing it. Kinematical relativity made the error of personifying coordinate systems and so endowing them with properties that could properly belong only to the objective universe. The cosmological presumption made the opposite error. It transferred to the universe the wider characteristics which relativity had found to belong to coordinate systems. Because coordinate systems, being pure fictions, were all precisely equivalent so far as objective validity was concerned, the cosmological presumption declared that *all aspects of the universe* must be precisely equivalent also. It is like saying that because all languages are equally valid for stating the propositions of Euclid, therefore all the propositions of Euclid must be equivalent to one another. The essential distinction between the objective world on the one hand and the rational observer of it on the other, which, I repeat, has always been fundamental in science and which relativity restored and reformulated, is here again destroyed, and a purely imaginary characteristic is foisted on the universe and presented as a basic axiom of science to which general relativity must yield place.

The next step is obvious. The appearance of the universe must remain the same. But observation seems to show that the universe is scattering apart. Therefore matter must be in process of creation all the time, at such a rate as to compensate for that which recedes from observation. This consequence of the presumption has proved specially attractive, for it has given rise to an alternative scheme in which it is itself taken as a fundamental postulate, without even the support of the baseless cosmological presumption. In this variant of the " new cosmology ", as it has been called, and as I will for convenience call it here since it is not literally inaccurate, it is simply asserted as a primary axiom that matter is continually being created.* Something akin to the cosmological presumption then follows by the reverse process of reasoning, for the rate of creation is guessed as being just that at which matter disappears by recession; hence the general aspect of the universe remains the same at all times. This is said to conform to the principle of the field equations of general relativity, for you have simply to make a slight change in the tensor on the left-hand side, and the right-hand side will then describe a universe in which creation takes place continually.

I am here again faced with the difficulty that I cannot give a true account of this new cosmology without appearing to ridicule it. I am doing nothing of the kind. I am simply divesting it of the symbolic clothing in which it has been wrapped for formal presentation, and the substance underneath appears ridiculous because it is ridiculous. It is hard for those unacquainted with the mathematics of the subject, and trained in the scientific tradition, to credit that the elementary principles of science are being so openly outraged as they are here. One naturally inclines to think that the idea of the continual creation of matter has somehow emerged from mathematical discussion based on scientific observation, and that, whether right or wrong, it is a legitimate inference from what we know. It is nothing of the kind, and it is necessary that that should be clearly understood. It has no other basis than the fancy of a few mathematicians who think how nice it would be if the world were made that way. The

* *M.N.*, **108**, 372, 1948.

mathematics *follows* the fancy, not precedes it; the fancy is credited because it gives scope for mathematical exercise, not because there is any reason to believe it true. Here are the actual words of one of the originators of the scheme: "Equation (10.5) [Einstein's field equations] may be read either from left to right, showing how the presence of matter affects the geometry, or from right to left, showing how the density, momentum and energy of matter must satisfy the well known conservation laws owing to their relation to geometrical quantities which are automatically conserved."* Remembering what the two sides of the equations mean, we see that what is here asserted is this: we can either observe how the universe behaves and choose a tensor that describes the observed behaviour, or we can construct a tensor having whatever properties we like and infer that the universe behaves accordingly. And, in fact, this second alternative is the one chosen in this second form of the new cosmology. A tensor is invented whose divergence does not vanish. This is substituted for the left-hand side of Einstein's field equations, and the divergence of the right-hand side must therefore also not vanish. The right-hand side describes the observable behaviour of the universe. Hence the universe must be such that matter is continually being created in it.

How is it, we may well ask, that such a thing is possible after three centuries of scientific progress in which it has over and over again been exemplified that the speculations of even the most gifted of seers go far astray from the reality that observation is to reveal? The question is a psychological one, of course, but it is not out of place to ask it here, for the answer may help us to understand still more clearly what value to place on these chimeras. So far as I can judge, the authors of this new cosmology are primarily concerned about the great difficulty which must face all systems that contemplate a changing universe, namely, how can we conceive it to have begun? They are not content to leave this question unanswered until further knowledge comes; all problems must be solved now. Nor, for some reason, are they content to suppose that at some period in the distant past something happened that does not continually happen now. It seems to them better to suppose that there was no beginning and will be no ending to the material universe, and therefore, tacitly assuming that the universe must conform to their tastes, they declare that this must have been the case.

But if we must really answer all questions immediately, is their solution in fact more intellectually satisfying than that of a special creation? Consider what it implies. Granting for the sake of argument that the nebular red-shift indicates that nebulae are continually receding into inaccessibility by surpassing the speed of light, we are then asked to believe that isolated fundamental particles are continually created within the accessible region in order to maintain the same total quantity of observable matter at all times. One immediately looks for a connection between these two processes. We are led, for instance, to suppose that when a nebula reaches the speed of light its particles might undergo a number of gigantic quantum jumps back into the observable region, something like those pictured in Bohr's original theory of spectra. But this appears impossible, for a nebula, on reaching the speed of light for us, is still observable from another nebula not so far distant in the same direction, and the process would have been observable there before becoming knowable to us. Hence the sudden vanishing

* H.B.C., pp. 95–6.

of nebulae moving at relatively slow speeds should be observable from one nebula, and therefore from all. No such phenomenon, however, is postulated in the scheme. It seems, therefore, that the recession of nebulae into unobservability and the creation of particles relatively near at hand must be independent processes. Yet they occur at exactly the same rate—not approximately, but exactly, for the universe must appear the same eternally—eternally in the past and eternally in the future. Such an extreme example of pre-established harmony—if the new cosmologists will forgive the phrase for what they will perhaps regard as an accident—is, to my mind at least, harder to credit than a special creation in the past. If I must choose I choose the latter as the less revolting to common sense, but on the whole I prefer that wise, ingenious and modest sentence, " I do not know ".

I cannot help wondering what would happen if the new cosmologists turned their attention to biology, for here there is a very similar problem. We observe living matter and dead matter, but we never experience the creation of living matter out of dead matter alone. We seem here to be faced with the same two possibilities as in cosmology : we can suppose either that, at some epoch in the past, dead matter somehow became alive by a process not yet known, or that the process has been going on eternally, but at such a rate that we cannot detect it. Since the former alternative is " against the spirit of scientific enquiry ", the new cosmologists would seem forced to postulate the continual animation of matter. But their own cosmological scheme rules this out. The matter of which the Earth is composed is supposed to have been created as separate atoms, and therefore could not have begun to live for many millions of years. Hence terrestrial life, if it is admitted to exist, must have begun at some particular epoch. There seems to be no escape from the difficulty except by denying the existence of living matter or by violating " the spirit of scientific enquiry ". I fear that the excessive inbreeding, which is the curse of mathematical physics, is responsible for the oversight of this problem.

But if inability to see science as a whole blinds the authors to the difficulties in their scheme, I think it is lack of historical perspective that allows it to be invested with the false charm by which they are fascinated. In every age there is a certain climate of opinion that predisposes thinkers towards a certain type of view and makes it very difficult for them to resist arguments that conform to it. This could be illustrated by examples from any period in history. I will merely mention the philosophy, of which I myself am old enough to remember the later stages, which sought to explain everything in terms of matter and energy; Haeckel's *Riddle of the Universe* was a typical representative of this view. There was a fundamental basis of *substance* : this was neither creatable nor destructible, so all phenomena must be caused by its change from one form to another. Life, therefore, was simply one of the forms assumed by this substance, which in another form was kinetic energy and in another, electromagnetic strain. Hence freedom of the will was an illusion, all actions of living creatures, even the highest, being as rigidly determined as the motions of the planets.

Today this way of thinking makes little appeal; our prejudices are different. Now it is the exceptional that is out of favour. By a sort of cosmic democracy we are predisposed to deny any unique characteristic to anything, and whatever we happen to see now, all the universe must see at all times. To think otherwise is to be pre-Copernican. And just as universal determinism could point to the

triumphs of Newtonian mechanics as demanding its dogmas, so this new view can point to general relativity, with its equivalence of status for all coordinate systems.

In these circumstances the voice of science is now as it has always been: "Never mind what seems the proper thing to believe; what is the *evidence* for what you say?" And the answer which the new cosmologists must give is just that which was available to the universal determinists, namely, "None at all". When you ask for the evidence that the movements of living creatures are determined, the first thing to decide is, what is a living creature? And the only answer we can give is that it is a piece of matter whose movements are not determined. Subject a mouse to given forces, and calculate how it will move. If it moves that way, it is dead; if it does not, it is alive. That is the only way we know of distinguishing between the two cases. Examined scientifically, therefore, the nineteenth-century argument ran thus: the movements of some bodies are determined, the evidence being that we have determined them; therefore the movements of other bodies are determined, although the evidence shows that they are not.

The cosmological presumption is in similar case. The great consequences that have followed our full recognition of the equivalence of coordinate systems predispose us to assert the equivalence of events at all places and times in the universe, but the evidence, such as it is, is all against it. Every process we know, on the small or the large scale, is a one-way process, showing a preference for one direction over the opposite. The system of nebulae expands and does not contract, gravitation is an attraction and not a repulsion, the entropy of a closed system increases and does not decrease, every chemical process tends towards a state of equilibrium from which the substances concerned do not of themselves depart, organic evolution proceeds in one direction and not the opposite; and so on. There is nothing whatever in nature that indicates that any course of events is reversible. Admittedly the evidence is small compared with the magnitude of the problem, but it is all we have. I accept the spirit of the cosmological presumption to this extent, that I do not believe that the universe conforms to the prejudices of the twentieth century rather than to those of the nineteenth. We shall be better employed in following the scientific programme than in listening to either.

I hope I need not say that none of the considerations I have put before you should tend in the smallest degree to diminish the importance that belongs to imagination in science, when the word is used in its true sense as referring to the ability to form vivid images of possible happenings, and not in the sense in which I have had sometimes to use it, as indicating the invention of arbitrary postulates. No great scientific work has been done without the free and bold exercise of this indispensable quality, and science will stop if ever it is treated as a branch of logic as surely as if it is given over to uncontrolled fancy. By all means keep imagination free, but let it be directed, and let its products be examined and properly assessed before they are announced as discoveries of the order of nature. Even idle speculation may not be quite valueless if it is recognized for what it is. If the new cosmologists would observe this proviso, calling a spade a spade and not a perfect agricultural principle, one's only cause for regret would be that such great talents were spent for so little profit. That would indeed be a sufficient calamity, but I am not without hope for the future. I am not yet

convinced that facility in performing mathematical operations must inevitably deprive its possessor of the power of elementary reasoning, though I admit that the evidence against me is strong. But I have a suggestion to offer. Let our younger cosmologists forget cosmology for a space of three years—the universe is patient, it can wait—and instead read the history of science. I do not mean books about the history of science, though they are infinitely better than nothing, but the works of the great scientists themselves; let them read Gilbert, Galileo, Harvey, Newton, Boyle, Black, Lavoisier, Faraday, Darwin, Huxley, Pasteur, Kirchhoff, Rutherford. Then let them spend six months thinking over what they have read and asking themselves what meaning it has for the work of today. And after that let them return to cosmology and give their attention again to the great problems into which they have prematurely rushed. I am convinced that if they would have the courage and the greatness of mind to do this, astronomy would not only be enormously the richer, but they themselves would thank me sincerely for the advice.

I know it is difficult. I can conceive vividly enough that when one's mathematical facility greatly exceeds his judgment of scientific authenticity, the temptation to exercise it indiscriminately on any premises that will give it scope must be overwhelming; and I am too sensible of my own good fortune in being free from that temptation to enjoy the task of arraigning its victims. But it is a task which I cannot escape. One who, however unworthy, accepts the honour of presiding over one of the foremost scientific societies of the world, accepts at the same time a responsibility. The ideas to which we give publicity do not remain our private possession ; they are accepted as genuine scientific pronouncements, and as such influence the thinking of philosophers, theologians and all who realize that in no intellectual problem, however fundamental, can scientific research now be ignored. And so, when it happens that we have published, in the name of science, so-called " principles " that, in origin and character, are identical with the " principles " that all celestial movements are circular and all celestial bodies immutable, it becomes my duty to point out that this is precisely the kind of cerebration that science was created to displace. And the responsibility is not only mine ; it rests on all of us. In cosmology we are again, like the philosophers of the Middle Ages, facing a world almost entirely unknown. We need to cultivate the restraint of Galileo, who left the world of angels and spirits until the time should come when it could be explored, and contented himself with such principles as he could extract with confidence from experience, though the resolution committed him to such trivialities as the timing of balls rolling down grooves. It is that self-control—the voluntary restriction to the task of extending knowledge outwards from the observed to the unobserved instead of imposing imagined universal principles inwards on the world of observation—that is the essential hall-mark of the man of science, distinguishing him most fundamentally from the non-scientific philosopher. It is the duty of all of us, now that the old temptation is with us again, to see to it that we preserve the spirit of true scientific inquiry which, as a scientific society, we are pledged to honour.

ELECTION OF OFFICERS AND COUNCIL

President

J. JACKSON, Esq., C.B.E., M.A., D.Sc., F.R.S.

Vice-Presidents

T. G. COWLING, Esq., M.A., D.Phil., F.R.S., Professor of Applied Mathematics, University of Leeds.

H. DINGLE, Esq., A.R.C.S., D.Sc., Professor of History and Philosophy of Science in the University of London.

W. H. MCCREA, Esq., M.A., Ph.D., F.R.S., Professor of Mathematics, London University (Royal Holloway College).

D. H. SADLER, Esq., O.B.E., M.A., Superintendent, H.M. Nautical Almanac Office.

Treasurer

L. M. MILNE-THOMSON, Esq., C.B.E., M.A., F.R.S.E., Professor of Mathematics, Royal Naval College, Greenwich.

Secretaries

A. HUNTER, Esq., Ph.D., D.I.C., Principal Scientific Officer, Royal Observatory, Greenwich.

Miss FLORA M. MCBAIN, M.A., Principal Scientific Officer, H.M. Nautical Almanac Office.

Foreign Secretary

F. J. M. STRATTON, Esq., D.S.O., O.B.E., T.D., D.L., F.R.S., LL.D., Emeritus Professor of Astrophysics in the University of Cambridge.

Council

C. W. ALLEN, Esq., D.Sc., Perren Professor of Astronomy in the University of London.

A. ARMITAGE, Esq., M.Sc., Ph.D., Lecturer in History and Philosophy of Science, University College, London.

H. BONDI, Esq., M.A., Lecturer in Mathematics in the University of Cambridge.

E. H. COLLINSON, Esq.

V. C. A. FERRARO, Esq., Ph.D., Professor of Mathematics in the University of London.

J. S. HEY, Esq., M.B.E., D.Sc., Senior Principal Scientific Officer, Radar Research and Development Establishment.

A. C. B. LOVELL, Esq., O.B.E., Ph.D., F.Inst.P., Professor of Radio-Astronomy in the University of Manchester.

R. A. LYTTLETON, Esq., M.A., Ph.D., Lecturer in Mathematics, University of Cambridge; *Geophysical Secretary*.

R. W. B. PEARSE, Esq., Ph.D., D.Sc., A.R.C.S., Assistant Professor and Reader in Spectroscopy, Imperial College of Science and Technology, London.

J. G. PORTER, Esq., B.Sc., Ph.D., Principal Scientific Officer, H.M. Nautical Almanac Office.

W. M. SMART, Esq., M.A., D.Sc., Regius Professor of Astronomy in the University of Glasgow.

G. J. WHITROW, Esq., M.A., D.Phil., Reader in Applied Mathematics, Imperial College of Science and Technology, London.

CONTENTS

PAGE

Anniversary Meeting of 1953 February 13:
- Fellows elected ... 269
- Junior Member elected ... 269
- Presents announced ... 269
- Address on the award of the Gold Medal ... 270
- Presentation of the Eddington Medal ... 270
- Presentation of the Jackson–Gwilt Medal and Gift ... 272

Report of the Annual General Meeting ... 273

REPORT OF THE COUNCIL TO THE HUNDRED AND THIRTY-THIRD ANNUAL GENERAL MEETING OF THE SOCIETY:
- Narrative Account of the State and Activities of the Society during 1952 ... 275
- Associate and Fellows deceased ... 275
- Report of the Auditors ... 281
- Table of Progress and Present State of the Society ... 281
- Treasurer's Accounts for 1952 ... 282
- Investments ... 286
- Gifts to the General Funds and Property of the Society ... 287
- Special Funds ... 288
- Trust Funds ... 290
- List of Public Institutions and of Persons who have contributed to the Library in 1952 ... 292

OBITUARY NOTICES:
- Charles Pritchard Butler ... 294
- Leslie John Comrie ... 294
- Peter Doig ... 304
- Herbert Henry Furner ... 305
- Richard Arman Gregory ... 306
- Theodore Mackenzie ... 307

PROCEEDINGS OF OBSERVATORIES :

	PAGE
Royal Greenwich Observatory	308
Royal Observatory, Edinburgh	312
Royal Observatory, Cape of Good Hope	315
Armagh Observatory	318
University Observatories, Cambridge	319
Cavendish Laboratory, Cambridge	321
University Observatory, Glasgow	325
Imperial College Observatory, London	325
University of London Observatory, Mill Hill	326
Radar Research and Development Establishment, Malvern	326
Jodrell Bank Experimental Station, Manchester	327
University Observatory, Oxford	331
University Observatory, St. Andrews	332
Norman Lockyer Observatory, Sidmouth	333
Dunsink Observatory	333
Dominion Observatory, Ottawa	335
David Dunlap Observatory, University of Toronto	337
Dominion Astrophysical Observatory, Victoria	338
Union Observatory, Johannesburg	341
Radcliffe Observatory, Pretoria	342
Nizamiah Observatory, Hyderabad	345
Solar Physics Observatory, Kodaikanal	346
Commonwealth Observatory, Mount Stromlo	349
Riverview College Observatory, N.S.W.	350
Sydney Observatory	350
Radiophysics Laboratory, Sydney	350
Perth Observatory	353
Geophysical Observatory, Christchurch, N.Z.	353
Carter Observatory, Wellington, N.Z.	354
Godlee Observatory, Manchester	354
Observatory of the Hampstead Scientific Society	355
Dr J. L. Haughton's Observatory, Charmouth	355
Mr M. B. B. Heath's Observatory, Kingsteignton	355
Mr F. M. Holborn's Observatory, Peaslake	355
Mr P. Moore's Observatory, East Grinstead	355
Dr W. H. Steavenson's Observatory, Cambridge	356
Mr H. Wildey's Observatory, Hampstead	356
Mr H. P. Wilkins' Observatory, Bexleyheath	356

REPORTS ON THE PROGRESS OF ASTRONOMY :

General Magnetic Fields in the Sun and Stars	357
Solar Activity : Sunspots	382
Prominences	382
Double Stars	384
Comets	386
Address delivered by the President, Professor H. Dingle, on Science and Modern Cosmology	393
Election of Officers and Council	408

Printed in London by Taylor & Francis, Ltd., 1953 *November*